

'HSOHWHG 8UDQLXP
7HFKQLFDO %ULHI



'HSOHWHG 8UDQLXP
7HFKQLFDO %ULHI

(3 \$ 5

'HFHPEHU

3URMHFW 2IILFHU
%ULDQ /LWWOHWRQ
8 6 (QYLURQPHQWDO 3URWHFW

2IILFH RI 5DGLDWLRQ DQG ,QO
5DGLDWLRQ 3URWHFWLRQ 'L'

LLL

) 25 (: \$ 5 '

7KH 'HSOHWHG 8UDQLXGPHVHBFQIGFWQ %RJQMH\LYDLOODEOH
DQG NQRZOHGJH DERXWBS\$BISDHQWLHDGO X3UDRQMLHXPWWORD QDJHUV 20
&RRUGLQDWURUV FRQWUDFWURUV DQG RWKHU \$JHQF\ PDQDJH
VLWHV FRQWDPLQDWHG ZLWK WKLV PDWHULDOW DGGUHV
FKHPLFDO DQG UDGLRORJLFDO KHDOWK FRQFHUQV LQYROYH
HQYLURQPHQW

7KLV WHFKQLFDO EULHI ZDV GHYHORSHG WR DGGUHVW WK
GHSOHWHG HSWBQ WDRUDGLRKIRJOLVOKDJDUG HGWG SWBYLGHV DF
DQG UHIHUHQFH VWRU DEGRQALKW WRKQHIDODVGRXRDQHJW FIBO DQG FKHP
FKD WDLFWWHKHDOWK VUUNH QFRQHEDOWRQ LWRKRU PDQV XHOGWP
DQG DSSOLFDEOH HWUHRDUWCHSQWHWHSKQWLDQ LXP

Please Note: This document has been changed from the original publication dated December 2 6. This version corrects references in Appendix 1 that improperly identified the content of Appendix 3 and Appendix 4. The document also clarifies the content of Appendix 4.

\$ FNQRZOHGJPHQWV

7KLV WHFKQLFDO EXOOHWLQ LV EDVHG LQ SDUW RQ DQ HQ
(QYLURQPHQWDO 3URWHFWLRQQ \$Q BQ, QG R2RIWF\$HLUR I 25D, \$LDZWLWK WKH
7ULQLW\ (QJLQHHULQJ \$VVRFLDWHV ,QF 7(\$ XQGHU &RQWUDFW
&RQWUDFW 1R +

7KDQNV JR WR 5RQ :LOKHDQPG 6B1GDIV0JLLQHWDDBUV RI 25,\$ DC
6DQGV :610XIBIWW5QPGELLUQ BQ. HDQ QHWK 26:Y5HORDUFHWRAHQDORG
VXJJHVWLRKQ VRDQOG JW(B\$MLQ DIO 5/W\$QJHOD &DUSHQWRHQU 55 5DQG\
'DYLG 'RULDQO5H &DPIQL DQGM1HRRUJLHD%UR]RZVNL 5 5LFN 3RHW

7 \$ % / (2) & 217 (176

385326(

, 1752'8 & 7 , 21

2.1 Characteristics of Uranium and Depleted Uranium

2.2 Health Concerns

([SRVXUH 3DWKZD\V
&KHPLFDO 5LVN
5DGLRORJLFDO 5LVN

85\$1,80 ,1 7+((19,5210(17

3.1 Occurrence

3.2 Geochemistry

3.3 Mobility

3.4 Enhanced Mobility

)\$7(\$1' 75\$163257 '23/(7(' 85\$1,80

4.1 Fate in Soil

4.2 Fate in Water

4.3 Fate in Air

4.4 Fate in Biota

4.5 Partition Coefficients

4.6 Fate and Transport Modeling

6,7(6&5((1,1*)25 '(3/(85\$1,80 &217\$0,1\$7,21
0(\$685(0(17 722/6 \$1' 021,725,1* 7(&+1,48(6
5(0(',\$7,21 7(&+12/2*,(6

7.1 Soil Technologies

3K\VLFD0 6HSUDWLRQ
&KHPLFDO ([WUDFWLRQ

7.2 Groundwater Technologies

3XPS DQG 7UHDW
3HUPHDEOH 5HDFWLYH %DUULHUV
&RPPHUFLDO 7HVW 6WXGLHV

7.3 Technologies for Soil and Water

,Q 6LWX 6WDELOL]DWLRQ 7UHDWPHQW
3K\WRUHPHGLDWLRQ
0RQLWRUHG 1DWXUDO \$WWHQXDWLRQ
(3\$ 67\$1'\$5'6 \$3,38/\$%/(72 '(3/(785\$1,80 6,7(6

8.1 For Soil

8.2 For Air

8.3 For Water

8.4 Storage of Depleted Uranium

8.5 For Disposal

\$FURQ\PV

*ORVVDU\

\$GGLWLRQDO 6RXUFHV RI ,QIRUPDWLRQ

\$SSHQGL[7HFKQLFDO %DFNJURXQG RQ 8UDQLXP DQG 'HSOHWHG 8UDQ
\$SSHQGL[HDVXUHPHQW 7RROV DQG 0RQLWRULQJ 7HFKQLTXHV
\$SSHQGL[1DWLRQDO 3ULRULWLHV /LVW 13/ 6LWHV WKDW KDYH RU P
\$SSHQGL['HSOHWHG 18DFDQXLXLPQ 0DDQQXG 7HVWLQJ)DFLOLWLHV
\$SSHQGL[&DVH 6WXG\ 1XFOHDU 0HWDOV ,QF 10, VLWH &RQFRUG
\$SSHQGL[&DVH 6WXG\ FODHBU)QDWSRVVDQ 6LWH +LOOVERUR .HQWXFM
\$SSHQGL[7UHDWPHQW 'HILQHG E\ 1&3
5HIHUGHQFHV

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XUDQLXPSRWHFGR RI WKUH&LVRWRSH

8 DQ& VHH 7DEOH > @ 7KH H

7HFKQLFDO %ULHIV DUH GHVLJSQURGF HMRV FFRQQYFHQ WUDQGHW KEHRWK W
DYDLODEOH LQIRUPDWLRQ DQGLVRQMRZSHTHG JLQ DNEKRHX WUDR GDX FW PDWH
SDUWLFXODU FRQWDPLQDQW RDWQWHSUHRVGW FWXR KLDQVSEURAGKX FW dep
GHSOHWHG XUDQLXP '8 WR WQBS(QYKLHU RQFQW DQW '8 UHWDLG
3URWHFWLRQ \$JHQF\ (3\$ 5HFSHTGHQFLDQW DQGD VOLJKWO'
0DQDJHUV 530 2Q 6FHQH &RJU\ DQDHWSJHUV BHQWDJHE\ RDVV
26& FRQWUDFWRUV DQG RWIKQWVWHLGH RFOHDQXS%HFDXVH RI W
PDQDJHUV LQYROYHG ZLWK WKH IWHH IDQGLQWFRS\ URH GBLWVWKH
FRQWDPLQDWHG ZLWK UDGLRDUF DQGLYRHDIP DMW M\W\Q\ V\& RLFLDWHG
DSSUR[LPDWHO\ OHVV WKDQ WI
7KLV 7HFKQLEQW\H\QGLTHG\ WWR KHQUSD\W\KXPHVHU
XQGHU\HW\W\KQDGU\W\KRW\HULVWL\ FV EHKDYL\RU LQ WKH
HQYLURQPHQW DQG SRWHQWL\G KXP\PDQ\KHDOWK\W\LVN\Q RDWXUDO
'8 DV D FRQWDPLQDQW LQ VRLOV DQG JURXQGZDWHU
7KH GRFXPHQW DQGLV\RDIE\Q\H\QWL\I\HW\RDY \$EXQGDQFH E\ ZHLJKW
PRQLWRULQJP\H\QW PM\RD\Q\W\HDQG YDULR\W\XUDO 8UD\QISXPHWHG 8UDQLXP
WUHDWPHQLW\W\H\RF\Q\Q\W\RRJQ RI VL\W\HV
FRQWDPLQDWHG ZLWK '8 6XSS\QPHHQWDU\
GLVFXVVLRQV DQG DGGLWLRQD\Q\ LQIRUPDWLRQ DUH
SURYLGHG LQ WKH DSSHQGLFHV

, Q WKH 8QLWHG 6WDWHV 8 LV DY
7KLV 7HDFK Q6WFLH L FVDSOHF\ DGGUHMURPV WKH 8 6 'HS DUWPHQW RI (QH
LQ DQ HQYLURQPDHQWLDOO VFRQWQWLDO KDWGDQJRYHUQ PHQW VRXUFHV '8
VSHFLILFDOD\ GRHV QRW FRQVQXGPHEUDLRUEQIOPHUVQW FRPSRXQGV
PLFUR SDUWLFXODWHQ BILWKKHFWDPSHPDWARFV ZKLFK PD\ KD
'8 PXQLWLRQV)XUWKHU LWLPSQFLWGRQDWHQDQWLWQ&QGRWSRV
FRQWDPLQDWQRQKVH BQDWHRGV6WDLWHDWHULDO
WKRXJK LW KDV XVHG LQWHUQDWLRQDO VFLHQWLILF GDWD
ZKHUH DSSURSULDWH IRU LW%WFDXVHDOEDWLRQDWH GHQVH WI
WKHVH HQYLURQPHQWDO FRQWBDPLGQDWLRQ YDQWVDEQDWIRWKHQGXV
PDMRU ULVN IURP '8 LV WR[LFRORQDXBQGMRQDWIRWKSDQUSRVHV I
UDGLRORJLFDO DQIGVFWKRLFFDORQWRVHDLWMM 'HWDLQHG LQIRUPDW
GULYHU IRU VLWH FOHDQXS LWV LFKDOP IRUPV PDQXIDFWXULQJ
SURFHVDQIG XVHV RI '8 FDWHRH&UWK

2.1 Characteristics of Uranium and Depleted Uranium

NQRZOHGJH WLFDW WUKRISIFKUHPL HWDQLXP LV D QDWXUDOORFFX
DGGUHVVG IRU QDWVWLDDOX WBRQHVKPDLQHDLOGHQRFNV DQG VRLOV
WKRVH RI '8 \$GCOOLCEGLVVXHG WR VHYHUDO KXQGUHG SLFRFXU
SHULRGFLDOO\ WR XSGDWH WKSH&RULJL\$OOOWKJIKQLEFWWRSHVDU
%ULHI ZKHQHGYQWFGHM/DU\ SURGXFH GHFKDSRSQURQGEWFWLHYH
GLVLQWHJUDWLRQ \$IWHU SXULILF
, 1752'8&7,21 XUDQLXP WKH GHFD\ SURGXFWV R
XUDQLXP LVRWRSHV XZOLDWHEMHLUQ V
HSOHWHG XUDQLXP '8 LV D E\QRZOXFWDQGWKDFHDX BU RVCKHAWV F
SURFHVV XVH\ XWWDQHQXWDFQKLQPD\UGXWHFWHG
QXFQHDU UHDFWRUV DQG LQ QXFQHDU ZHDSRQV 1DWXUDO

2 WKHU RWJB\$HVLWKDW KDYH E12 HealthChoices LQ
GHSOHWHG XUDQLXP DQG DUH OLNHO\ RI
DQWKURSRJH QIXFIRUQXW RQQF \$ FRPPRQ PLVFRQFHSQLRQ LV WKD
3X BQKXWP 3X BQKXWP SULPDU\ KD]DUG '8 SRVHV WR KXP
3X DPHULFL\$XP QHSWXQLXP V QRW WKHFRDWI [SQQM UHPVFHQD
1S DQG WHFKQFH WLXP 7KRXJK LUUDGLDWLRQ IURP '8 FDQ
WR[LFLW\ LV XNURXKODQD U\KURPPDVRO
7DEOH 5DGLRORJLFDO SURSHUWLHV P18UDOLXP
,VRWRSHV
GRPLQDWHV LQKDOODWLRQ RI VSaUL
6LQFH DORRIIRRUBQWVWKH VDPH
LQKUHQW FKHPLFDO SURSHUWLHV
WKHPHVDEHKDYLRRUV RI FQQRQLEDO W
LQWHUQDQD [DQG WBLDOGYDQVH KHDO
HIIHFVWUWLPRWOKRVH RIWDRWKHU KHD
7DEOH DERYH OLVWV WKH KDOXFKLHV RI HDPGRQGLQFWV
\$SSUR[LPDWHO\ RI WKH UDRGLRDXVWLDQFHWDQGWUHV DVHV
QDWXUDO XUDQLXP BV DVVLRFVLSWH ZIRWKFRORJLFDO 3UQILOH
DVVRFLDWBGDQGLWK LV DVVRFXBWDQFLHV WCKPDIQ[LDQVGLQXPDQ GD
ZLWIS \$OO WKUHH LVRWRSHV REQKADKYH WRKHFRDPRH\ RI QDWXUDO
FKHPLFDOO\ EXW KDYH GLIIHUHQW UDGLRORJLFDO
SURSHUWLHV \$V PD\ EH FDOFXDQWVH[DQG WCKS QHWEHG XUDQLX
WKH UDGRLRDO\WWUDQUDQLXP UHODWLYH FRQFHQWUDWLRQV RI
DSSUR[LPDWHO\ J ZKHUHDV WKHSOHWHG XUDQLXP LV URXJKO\
UDGLRDFW'8YLW DSSUR[LPDJWHOPV QDWXUDO XUDQLXP EHFDXVH W
LVRWRSHV KDYGH E\$OHOQ WKRIBRMHQDW
7KH ZHLJKW SHUFHQWDJHV LQ RFDPEXOUHJLQJDQGUDQLXP LVRWRSHV
UDGLRDFWLYLW\ SHUFHQWDJHV DQJLQHLSUHULPRDXWOU DDGULHDWLRQ %
GLIIHUHQVM EHFRWWR\\$H KDV D GLSIPWQFAHV FDQQRW SHQHWUDWH
SK\VLFDOKDOI OLIH DWWKJHV VKRUVWBIOOKDFOQVLIQHJHG DQ LQWHUQ
8 WKH PRVW UDGLRDFWLYH DQG] DNUKH UDRQKJH\W WKOQDQH[HWHUQ
PDNH\\$ WKH OHDVW UDGLRDFW\$ZBHUHOPFKVLRQWSBQEHG RDHJDUGLQ
GHFD\W E\ HPLWWLQJ DQ DOSKID[WBLWQDPOKD]DUG VLQFH '8 FDQ F
DPRXQW& DRQG RWKHU VXEVDQFH
)RU QDWXUDO XUDQLXP SUHVHSQWVWQQLRIPQDQGLBIRFIVDQG WHF
WKH DFWL\$DQWV\WURHI LGHQWLFDQZHYKHW WKH ULVN SRVHG E\ WKH
DUH VDLG WR EH LQ VHFXODU FRQWQDQFLQDWV, QVQDWXUDO\ UHJD
ZDWHUV KRZISYHDOQ WKSJHDU WQEMHLJQLILFDQW
VOLJKWO\ PRUH VROXEOH DQG WKH UDGLRDFWLYLW\ UDWR
RI 8 WR8 YDULHV IURBH WKMDQ PR ([SRVXUH 3DWKZD\V
7KLV LV EHOLHYHG WR EH8QDQWLRPWRFXUDQWLRKOWLQW WKH
8 GHFD\WLRW SDVVHV WKURXQKWRQVXUDO OHYHO RI XUDQLXP LQ
7K first decay product DQG WKH QUDQLXP LQ DLU ZDWHU DQG VR
SURWRDFWLQ\\$ second decay LQKDOHG HYHU\ GD\ 7KLV QRUPD
product ZKLFK DUH WQILJRKVQVEOPHRWQBWXUDO OHYHO RI XUDQLXP LQ
WKH XUDQLXP L8RWKRSVHDSKBDQSWR[LPDJWHQ ([FHVV ORDGLQJ
PRYH ZKLOHUMKPHDLQV VSDULQJWKRQXHEH H MSIRWDQWLDQD WLRQ
:KHQ FRQYHUWLQJ IURP DFWLQWVWLRPQDQVWQGU GHKURDIO FRQWBE
YHUVD NQRZOHGJH RI WKH FRQHUVWDXDQDQFRRQVHOLFHUHG WR E
WKH WKUHH XUDQLXP LVRWRSHVQVWQHITFDQWGH[SRVXUH VFHQDU

, QKDODWLRQ LV WKH WBRWW ROLSHUROY LURRQORUJXILQHOLQH IRU GUL
'8 , Q WKH FDVH RI VLWHV FRQRWDPLAQDDWMQOZLHWKRQVLGHUHG WR
WKLV PD\ RFFXU WKUHQWKRQVLGHUHG WRQQLFDUOHQDO UHQDO HIIHFWV
DWPRVSURFHGXWKRQVLGHUHG WRQVLGHUHG WRQQLFDUOHQDO UHQDO HIIHFWV
GXH WR VLW\$FIRLSGHUQWIDQQLQK D500DGWLRRQFPDQGHV LQVHULQNLQJ :DW
DOVR RIFDQJQDVTXHQFBI RI ILUPDQPDQFLRQDQWDP OHYHO IRU QDWV
VWRUDJH IDFLQUDWVWDQXUFLDUFBNMFKWURQJ XUDQJLXPDDQWLWV
DURPU SLHUFLQJ ZHDSRQV RU \$KHQGHLFLRQWDRPQFLBLBQLRLQ JRD
RI FRQWDPLQDWG REMHFWV 6XSQHUIXQG LV 8 LQJWD\$QUDWHL
7KH 1XFSHDXODWRU\ &RPPLVVLRQ¹
, QJHVWLRQ FDQ RFWXLQRQIDDOBEBMSDWLRQDO WQHQHDOS/QLPRLWRC
FRPPXQLSRSRQDWLRLQDLWHLWIRQNLQJHVWLRQ LV PJ
IRRGVXSSOLHV EHFRPH FRQWDPLQDWHG ZLWK '8 , Q
DGGGLWLRQ LQJHFVWLORGQUHRQVRLQ E 5DGLRORJLFDO 5LVN
FRQVLGHUHG VDL\$QWHLQDWQDQDQWIKZDQHUDO SRSXODWLRLQ LV H[S
> @ SULPDULROXJRKQDQG ZDWHU ZLWK D
DYHUDJH DQQXDDQDQWLDHNMHDILWLRPVRX
'HUDO WBRQW LV FROODWGLYHUONG DEHHQJWDERXS&L@ > 2Q DYHUDJH
XQSRUWDQW VVWSHVIRQFHQSQVWWDQHSBRWLRQWHPOLFURJUDPV RI XUD
'8 ZLOO SDVV DFURWAKIEQVKRHGVNLHQLLVQWRLQ WKHKXPDQERG\ IURP
+RZHYZHUFRXSOGWVWQWLPWFLQDWLRLQDWHLU IRRG DQG DLU \$ERXW
WKUKRQSZHRXQG VUHRQG G H G VNHOHWRQ LQ WKH VLYHU L
IUDJPHQWV RI '8 > @ DQG QRWKHU>W@VVQHWKH 8QLWHG
6WDWHV WKHWISLFDOFRQFHQWU
&KHPLFDO 5LVN WKHVNHODVWUXFWXUHZHW
:KHQ LQFRUSRUDWLG LQWRWIKSHLE RQG@> WKKH KQHJQHJMDQH
FRQFHQWUDWLRLQV RI XUDQLXPUHFRFLXVHLQVWKLQJLJKLJNKLQWHDQDQXDO
WKH PRVW VHQLWLQH RUJDQIUDRPZHUQDQWDLWHPDWHIG WVVXH
DQGVNHOHWDQDQFWRWUH8 PUHP UHVSHFWLYHO\ IRU 86 UH
VXEVHTXHQWO\ DFRVRGU DQG LQWRWKHEO
GHSRVLWHGLQWKHNLGQHV\ \$RUWRKHFDA R'8JDQ\ LWVGHFD\ SU
GHSHQGRQWHYHUDO IDFWRUVDJSKDHESRWDUQGJDPPDUDGLDW
SDWKZD\ SDUWLFOHVVLJHVRLQXEHVWQDQG'DQWHUQDO H[S
SDUWLFOHV DQGR[IEQHQWKBIVWHDQDQHGOHQRWKHQFRXQWHU '8 FRQWD
GLIIHUhQW VROXELOLWLHV 7KHDWKGHRQXWRQJXHJRW [WQHMKVROG
RI SULPDULFRQHDFQG282DUH PRGHO DQ\ DEVRUHEGGRVH RI XU
UHODWLYHO\ LQVROXEOH > @DVQXRA&GEWORIDQGXQ\$MDUQDQ\LQFU
VROXEOH XUDQLXP FRPSRXQGVLQDQFH EXHUQDQHLYXHPGWHQGDYHFRQFH
OLWWOH SRWHQWLDDXWRFIRDXXQHRIQDQWRQFQFWWH ERG\ WKHUL
FDXVHSXOPRQNDKUURWQDQFLDQWRQERQH OLYHUVXDFQGD\$QORHRXGNHPLD
H[SRVXUH > @ EH LQFUHDVHG

7KH LQJHVWLRQ H[SRVXUH SDWQKZDQHEDQWMLQWQVWKDQW UHVLGH
QXPEHU RI HVWOLEHOLKHDQGLWWRQGDSHGV RGV RI WLPH PD\ GDPPD
IRU FKHWRFIDQDQW5 KDPVQDQDQDQW LQFUHDVH WKHO\$QVFLDEQDQHLDQW
ULVN OHYHO IRU LQWHUPHGLDQWQGKHQWMLQDQDQG DOWKRJXKJWV
VHW DW DQ RUORIXSMWDQNLHXRISHQWMLQDQDQG DOWKRJXKJWV
RI ERZGHLJKW SHUGDRUQVKRXJKUWQDQDQG DOWKRJXKJWV
+HDOWK2UJDQLJHDDWLRIQWDEOLQGKHQWMLQDQDQG HPLWJDPPDUDV
WROHUDEOHGDLO\ LQWDNH 7', IRU XUDQLXP RI
—J NJ ERGBJKW SHQDQD\ D

7KH DPRXQW RI XUDQLXP LQ WKH DLU LV XVXDOO\ YHU\ VPDOO DQG HIIHFVLYH~~Q~~LLDQVLJQLILFDQW IRU UHP RSHUDWLRQV 3HRSOH ZKR OLYH QHDU IHGHUDO JRYHUQPHQW IDFLOLWLHV WKDW SURGXFHG RU WHVWHG QXFOHDU ZHDSRQV LQ WKH SDVW RU IDFLOLWLHV WKDW PLQH RU SURFHV VV XUDQLXP RUH RU HQULFK XUDQLXP IRU UHDFWRU IXHO PD\ KDYH LQFUHDVHG H[SRVXUH WR XUDQLXP)ORH~~Q~~PLBWKH 8QLWHG 6WDWHV DQG &DQDGD KDYH VKRZQ HOHYDWG XUDQLXP OHYHOV LQ DQG DURXQG PLOOLQJ DQG SURFHVVVLQJ IDFLOLWLH~~W~~DQG~~Q~~ LHUVRLUPQH UHOHDVHV RI XUDQLXP DW RQH '2(IDFLOLW\ DPRXQW HG WR NJ EHWZHHQ DQG ZKLFK SURGXFHG DQ HVWLPDWHG RIIVLWH LQYHQW RU\ RI NJ RI H[FHVV XUDQLXP LQ WKH WRS FP RI VRLO LQ WKH YLFLQLW\ RI WKH IDFLOLW\ > @

85\$1,80 ,1 7+((19,5210(17

'XH WR LWV QDWXUDO DEXQGDQFH XUDQLXP FDQ EH IRXQG DQ \ZKHUH LQ ZDWHU LQ IRRG DQG DLU %HFDXVH '8 DQG QDWXUDO\ RFFXUULQJ XUDQLXP DUH FKHP LFDOO\ WKH VDPH NQRZOHGJH DERXW WUDQVIRUPDWLRQ WUDQVSRUW IDWH DQG HIIHFV RQ QDWXUDO XUDQLXP LQ WKH HQYLURQPHQW LV DSSOLFDEOH WR WKH VWXG\ RI '8

3.1 Occurrence

\$V DQ HQYLURQP HQWDO FRQWD PLQDQW '8 P RVW IUHTXHQWO\ RFFXUV DV WKH PHWDO DQG DV D QXP EHU RI VROLG R[LGHV ZKLFK PD\ LQFOXGH WKRVH DULVLQJ IURP R[LGDWLRQ RI WKH PHWDO WKRVH IURP K\GURO\VLV RI XUDQLXP KH[DIOXRULGH DFFLGHQWDOO\ UHOHDVHG WR WKH HQYLURQPHQW DQG WKRVH IURP QHXWUDOL]DWLRQ RI DFLGLF LQGXVWULDO ZDVWHV WKDW FRQWDLQ GLVVROYHG '8 ,W FDQ DOVR RFFXU DV VROXEON DTXHRXV VSHFLHV SULPDULO\ WKH XUDQ\O LRQ RU DV D QXPEHU RI LQ VROXEON DQG VSDULQJO\ VROXEON VSHFLQ\HUDQ\WFRXQPLQJ P KDYH DULVHQ DV DV UFHRVPSOO\ RI XUDQLXP HQYLURQPHQWDO FKHPLVWU\

3.2 Geochemistry

2[LGDWLRQ UHGXFWRQ SURFHVVHV SYG“Q=—ÅHR PHQ]\QW0 s Ð QYQ HQYLX RQ PQ• P0€PÀ WKH D UHV

VROXELOLW\ GXH WR WKH SUH*VLYQHQH VRK HF ROPRSQJH KDDQW VOLIH RI XU
OLJDQGV DQG RU FKHODWRUV GHLFODH WKHQ B TXSIRUXWLFXODUO\
SKDVH LQ JHQ HUDO PD\ EH DEOMHW B QHQ SWIRIDQIVIS RYHUWULQ WKH HQ
WRUWXRXV SDWK WKGLRDX ZKKHMKR QJQIRZLRLQJL FVHPHWLRQV GLVFXVV '8
FRQWDPLQDQW DWWDFKHG WR PDHSDXURWLFOH WKDW LV WRR
ODUJH WR WUDYHO WKURXJK WKH VPDOOHU SDWKZD\V LW LV
HIIHFWLHYHO\ ZLHGVRPUNIEBDNQHGG WR**4.1 Fate in Soil**
FUHYLFHV WKXV JLYLQJ LW DQ SHROQK\ QBLWCK HPURLEQJOLQVRQ R[LGL]HG
& ROORLGV DQH WSSDLQFOOLQQJ\ WWKHP\ VLJHH DGVR UEHG WR FOD\ PLQH
UDQJH IWWRHPORBX OHDVO\ OV\ RE LVRPO RJ\ T\ B\ OV\ XUIDFH V RI UHPDLQLQJ '8 IU
HQWLWLHV VXFK DV EQFWB\OL\ BH [SSRDWHL\ M\ ORH W\ RH\ \D WPRVSKHUH ZL
DQG RU RUJDQLF PDWWHU WKDXWDFQDQX\ HR\ DG\ Q\ W\ X\ V\ S\ H\ Q\ G\ H\ G
LQ WKH DTXHRXV SKDVH ZLWK\ B\ M\ D\ Q\ V\ F\ O\ D\ Q\ J\ [L\ A\ M\ H\ L\ Q\ D\ W\ K\ H
EH K\G\W\R\OSURGXFWURJD\&W\B\Q\LR\PL\G D\WW\RI\Q\ V\MD\B\G WD\W\H\K\H\H
FKHODWHV QDWXUDO DQG DQ\W\RX\W\VR\B\IRQ\H\Q\W\K\I\Q\Q\W\Q\G\W\H\Q\W\H\H\J\ R[LGH
PLQHUDO R[LGH KXPLF FROORLDGUH R\Q\O\U\N\B\Q\H\ E\X\W\Z\LOO\J\UD\G\

) \$ 7 (\$ 1' 75 \$ 163257 2)
' (3/(7(' 85 \$ 1,80

I R U P G K A D G W X U D Q L X P P R R L V V H V L Q
F R Q G L W L R Q V D W P I G H X R Q P Q L Z L P O O
W K H Q V G O L R V Z O R I O Y H D Q G E H W U D Q V S
V X U U R X Q G L Q J V R L O S R U H Z D W H U

(QYLURQPHQWDO FRQWDPLQDWURQEGZBWFHQDQFDFRJKURIXDIQLDXGPVWRBLQVRLOZDWHUELRWDDQGRDUJDQUREFRQPHRSXQDQWLLFOOXHWEKMWWRKLH\$OWKRXJKWKHUDGLRORJLFDCDSWNSRHUMLJHWDWLRLQDQMXAKRXOGLVRWRSHVGLQHUV~~FRQWDFDQH~~UDERUPXUDQ\OLRQFDQEHDGVRU
EHKDYLRLU LV HVVHQWLDOOLCRHJQDWQE\DFRPSHQXFQHGVDQGODWHUNQRZOHGJHDERXWL~~RVQHW~~WUDQOASLRV~~W~~DFHGEIRWKHUFDWLRQVIDWHDQGHIIHFWRIQDWXUDQJUJDQDFXPDLVQHMVKDQVQDQHGXRFHVWVHKHQYLURQPHQWLVDSSOLFDEOHWRU~~P8MF~~KDUHQRWOLNHO\WR
EHWKRXHJKRNKIKWVVFHTXIPREWGQ\1HG

8QGHU VRPH FRQGLWLRQV V XDFQGDR/DW KHV RUQHGEXOFH Q J
FRQGLWLRQV FKDUDFWHULVWLFRIVZDPSVDQG
ZHWODQGV WKH VWDEOH FKHPQFWKHIFDVRIRUWDPHQHDXPOWLRKHS DR [LG
WKH QZKDLWKR LW ZLQGLVQRRNQYHIDWHOGHSHQGV RQWKBEDGEPWQWVLJH
LQ ZDWHU DQGHZLQHQDWKXWHDHFRLPQVWXUHFRQWMLQWVWRLLQFKHP
IPPRELOH 8QGHU R[LGL]LQJ FRQWQFLRQQWHQ/WFIDQG WKH SUHVHO
RQ WKH VXUIDFH RI WKH JURXQG WKLHQVRLKDVQZKHZDQNGWCHLUVROYHO
'8 R[LGL]HRVHDHVWODZKQLFGKLWRDHFHDUEERQDWHRFRQFHQWUDWLRQV DU
DQGEHFRRLPQHPLQZDHWHRWUP0HWWDROSORLUWDQWIDQWRWURHSDQGLQRXHQF
ZLOO R[LGL]H IDVWHWWDQVBDQHKSIDYULWRLFQBM&LO > @
ODUJH SLHFHV > @

,URQ DQG PDQJDQHVH R[LGHV VP
\$VLGH \$URP QXPKEHIUUDSHDRHUV QDWXUDOORFFXUULQJRUJDQLF
DIIHW XUDQLXP IDWIKHDQG WUDRQPVHSRKUDW LUUHYHUVLEOH VLQNV
SDUDPHWHUV WRKDHV HLOQWODIHIQ FVHRQPVRLOV \$SWDLRQIVRXQOWR VBRHQ D
SUHVHQFH RURUDJEDVQHQFFHRPRRIXQPGD/QJDQHVH R[LGHV FDQEHDQH
UHGR[VWDWXV OJDQGF RQFISQWIEHDVWVJRKDQWVHRSUHVHQFH RI GLV
FDUERQDWHI OXRULGH VXOIDFWDHUEBQDQWVSHKDFWQRLDQWVGE L WUDQILXP
GLVVROYHG FDUERQ DOXPLQXVUDQDQIGHW UERHQW EHLHGQH WKHVH ERXQ
PLQHUDO FRQFHQWUDWLRQV DQGVXRLUDYQHLGXSKDVHLV VXE MHWFW W
FRQFHQWUDWLRQV UDWHV > @

OLFURELDO DFWLYLW\ PLJKW VSHHG XS WKH FRUURVLRQ
RIPHWD OOLF '8 EXW LW VKRXO GUDQQRWQVWRDWWKHLQJKFRPS
WLWDSQLHVKPHQW LDQW& QI RULJL FDUE RQDWH LRQVLQ FVRQDXRNQLDRQH 7
W\SLFDOORXOG WHQGUDRWF DQH PSONHTWDLVQH WKH VROXELOLW\
VORZ GRZQ WKH SQRW K M VR WKURQDQG IDFBQLLGDDMLHRQ DQG LQF
LQ VRLO ZLWK KLJK FRQFHQWUDWLRQ&P RIREUQDWLF\ OLP LWLQJ
PDWHU IXDUOVOOQ DRWTF DFWHOLWDQER[LGL]HG ZDWHUV > @)OXRI
UHGXFH VRQWRE QIS DQURQKJEOAH 8 DQG VXOIDWH OLJIDQFQVWDOQ DOVR
WKHUHMLQJPKUDQLXP PRELOLFRWPSQHZ[H]QDQ\O LRQV > @
2[\JHQ FRQWHQW SUHVHQFH RI ZDWHU VLJH RI WKH
PHWD OHSVD USW\HRSQURHWHF WLYH \$WRQWRZQJRLF VWUHQJWKV ZLWK C
DQG WKH VDOLQLW\ RI WKH ZDWHU WSKJHFRQWHQDNUB\ BQWRI GLV
WKH UDWH RI PLFURELDO DFWPRQWQDFRKQWQH[KED]QJH DQG
NQRZQ WKDW RUJDQLF PDWWHDUGLVRQDSWLQRIURKUHQHXP \$V WKH
LQ VRLOVHDQWGV VMQKHP DFWXDO VPRQKXWQRFQWQHDFDHWLRDQV H J
WKH SURFHVV LV VWLOO XQFOHBU-> G@VSODFH DQ\ XUDQ\O LRQH[FKDQJH VLWHV DQG IRUFH WKH
VROXWLRQ

4.2 Fate in Water

8 VROLG SKDVHV KDYH UHODWLYHO\ ORZ VROXELOLWLHV
VR WKH WRWDO F~~R~~^Q F~~Z~~^Q DQWHUD W~~V~~^W RQ RI 8
XVXDOO\ ORZ P J / > @ \$ W~~Q~~^W RQJMSKHHWD~~B~~^B D~~U~~^U H~~D~~^D UHHWD~~M~~^M VP RR I
DTXHRXIR~~18~~¹⁸ PV SUHFLSLWDWHV W~~I~~^I K~~F~~^F O~~X~~^X V~~L~~^L Q~~H~~^H O~~S~~^S W~~U~~^U E~~Q~~^Q D~~O~~^O WH IRUP DV
VROXE OH DGVRUEV VWURQJOJ~~W~~^W R~~P~~^P L~~U~~^U PHUB~~B~~^B O'8V~~Q~~^Q UHD R~~R~~^R W FRPPRQC
DQG SDUWLWLRQV LQWR RUJDQKH K~~P~~^P L~~U~~^U W~~G~~^G H~~U~~^U Q V~~S~~^S W~~W~~ R~~R~~^R D~~U~~^U K~~Q~~^Q F~~R~~^R D~~W~~^W H
SURSHUWLHV OHDG WR LWV UH~~E~~^E P M GO~~P~~^P R~~E~~^E W~~Q~~^Q L~~W~~^W K~~H~~^H Q~~L~~^L D~~W~~^W H~~U~~^U D~~Q~~^Q V~~S~~^S R~~R~~^R
VP D O O O~~S~~^S H~~U~~^U W~~S~~^S D~~U~~^U H~~U~~^U H'8 FDQ RFFX~~I~~^I
8 QGHU UHGXF~~L~~^L QJ ~~I~~^I F~~R~~^R Q~~Q~~ G~~K~~^K LHW~~G~~^G R~~R~~^R Q~~Y~~^Y Q~~D~~^D Q~~W~~^W L~~V~~^V L~~R~~^R Q IURP VWDFNV UH V~~U~~^U
R~~I~~^I LGDWLRQ VWDWH LQ DTXHR XWR~~W~~^W R~~O~~^O R~~X~~^X W~~W~~ R~~K~~^K Q~~U~~^U R~~X~~^X J~~K~~^K H~~G~~^G P~~F~~^F V~~U~~^U R~~Q~~^Q V R~~I~~^I
FRQGLWLRQV DUH IRXQG LQ G~~H~~^H Q~~H~~^H D~~V~~^V T~~X~~^X L~~U~~^U H~~Q~~^Q G X V~~P~~^P D~~U~~^U R~~K~~^K SURFHVV D~~U~~^U
DUHDV DQG HQJLQH~~N~~^N UQHGWE D~~U~~^U L~~H~~^H U~~V~~^V 8
VWURQ~~S~~^S O~~H~~^H F~~H~~^H P ERQF R~~R~~^R R~~U~~^U J~~D~~^D Q~~L~~^L F~~6~~⁶ R~~X~~^X U~~F~~^F H~~H~~ V~~W~~^W L~~F~~^F N~~D~~^D W~~H~~^H O~~H~~^H D~~R~~^R W~~H~~^H V~~W~~^W D~~D~~ U~~H~~^H J~~H~~^H
OLJDQGV DQG H~~G~~^G H~~G~~^G R~~S~~^S U~~Q~~<sup>Q^W D~~Q~~^Q \ S~~D~~^D G~~H~~^H K~~U~~^U Y~~H~~^H G IURP VWDFN PRQLWRUV
8 2+ LRQ XQGHU S+ FRQGLWL~~R~~^R Q~~W~~^W A~~S~~^S L~~Q~~^Q F~~H~~^H Q~~X~~^X P~~D~~^D L~~R~~^R W~~X~~^X V~~H~~^H G WR H~~V~~^V
QDWXUDO Z~~S~~^S D~~U~~^U H~~F~~^F W~~S~~^S U~~R~~^R D~~P~~^P W~~H~~^H V~~W~~^W R~~U~~^U H~~O~~^O H~~Y~~^Y L~~D~~^D V~~H~~^H W~~X~~^X V~~S~~^S H~~Q~~^Q V~~L~~^L R~~Q~~^Q F~~H~~^H R~~P~~^P M~~R~~^R L~~O~~^O
UHODWLYHO\ LQVR~~Q~~^Q D~~Q~~^Q H~~Q~~^Q V~~R~~^R A~~Q~~^Q D~~A~~^A J~~W~~^W E~~Y~~^Y F~~B~~^B K~~Q~~^Q W~~V~~^V M~~S~~^S L~~U~~^U H~~Q~~^Q M~~D~~^D V~~S~~^S D~~O~~^O ` 0 Ä^ä j^ä "C
82 DQG FRIILQ~~L~~^L W~~H~~^H 86L2</sup>

\$ V SUH YL RQXWLRQ PIG L RQKVH RBD Q EH
UHPRYHG IURP VROXWLQRQ E\ VRUSWLRQ RQ LUR
K\GUR[LGHV DQG RUJDQLF VRLO PDWWHU 6RUEHG
XUDQ\O LRQV FDQ EH UHGXFWMQWRV8
VXFK DV K\GURJH Q PMHV\OKIDQHH & +
RU IHUURXV LUIRQWBE\ODUH VRUEHG

FRQFHQWUDWLRQV UHVXOWLQJLWRUJGWSHFRWWWRQURDQWLXHP PRYHF
DLUERUQH '8 ,W LV UHSRUW HIGQWIKUDRQ P HRQWW RKRWHYH'8 G WKH (3\$
GXVW ZLOO EH GHSRVLWHG ZLWKLULQVDWGLWWDVQFWHRIRIEHVVWZD\W
PHWHUV IURP WKH VRXUFH > @RQFHQWUDWLRQ RI SUHFLSLWDW
)ROORZLQJ DLUERUQH WUDQVSRLQW PHLFQDQLVPV
'8 ZLOO XOEWHFFRDPMHOXE MHW WRZRPSVRNQGV LRYROYHG GUDWKHU W
VRLO DQGLEDR WUDQVSRLQW PHLFQDQLVPV
JHQHUDO '8 GDHLSUREVRLWQHG VENDQVSRUW ZLOO
EH SUHVHQW RIQORVUX QHDFUHRMZH\$ VRZLWK RWKHU XUDQLXG SURSHU
PLQDOPXSW DQH\$ ERFVW QRW YDOXHV DUH VWURQJO\ LQIOXHQF
HIIHFWLYHO\ VRM DQKVKH\$ RFRKHDHQ WKUH S+ GHSHQGHQW VXUIDFH FKDU
DV ORZ OHYVWQHQLQJUDWVH PFKH VRLLQHUDOV DQG[VRKHFRRXPV
VROXEOH XUDQLEKPOVSHFLHV TVSHFLDWLRQ EHKDYLQRQ JRHQGHUVWQ
DW S+ OHVV WKDQ WKH DGVRUSV
VRLOV DQG VLQJOH PLQHUDO SKDV

4.4 Fate in Biota

6RPH SODQW PDWHULD DO VXF KF DQWDLFOXHQQJDFTDQQRXWUWRHOXWLRQV
DV DQ LQGLFDWRIERQIWDDLPULQRDUQPHQPLXP LQ DGVRUSWLRQ EHWZHH
/LFKHQV FRQVLVW RI IXQJL DQGHDFQHDDHVLOQJYDQW S+ YDOXHV JUHDW
WRJHWKHU V\PEXWWIDQDQOEHQKQDDEBIO SURYLGHV PLQLBXPDQG
ZD\ \$V HQLREKSKRORJ\ GRHV QRWDYDXWQDQWRXDV DIXQFWLRQ RI S
WKH VHDVRQV WKHLU DFFXPXO\DRQZLVRQKRH SREGIOXWDQDWLRQWDQW
RFFXU WKURXJKRXWXWKBIOQDOLYDHQG WKH\
IRU\YORRQJ SHULRGV

4.6 Fate and Transport Modeling

6RPH OLFKHQV JURZLQJ RQ WK2HE WIXRUXDTH RWK DQERHWWKHUPHWKRG IR
SODQW KLDQKHF DMSRD EDXWVH FRQFHQWUDWLRQ RI D FRQWDPLQD
XUDQWVH VDQHBR R WV QOLRVMH QRQGRDPLQDEWKGWHLWVHFLWLMFH
KDYH DFFHQWVWNLQDQWIDQG PHDVXUHPHQW XVLQJ WKH DSSUR
DFPQOBWXEVWDQFH VPDLQO\ YLPDH WVKURQDSBQCKSURRACRWFIRPQDQW
DWPRVSKHULF SDQWVWVODWHVFRQWUDWLQDQWVXWHKHQWVVGHW
DFFXPXODWHGLQOLFKHQWKDQDRXVIXQSHKUWQGRVSVWUDSRQGVHV 7KH
GU\ FRQGLWLRQV IURP DLVWREIDQHYDSQWVWLFH\H\QDGQQLDSISWBDWEIRQV
(YHQ WLDQJPHQWV RI OLFKHQV KPDYHFEGWQLZQHOOGLVFXVVHG LQ
FRQFHQWUDWLRQV WKDW DUH DQGQZLQHUGFRWPHPTFMQDGEVKDQW @KHZH
VKRXOG EH PHDVXUHGWHVWKLWPSF

4.5 Partition Coefficients

3DUWLWLRQ FRIHWIDFSBQDWPHWHVRSWGRQ SURFHVVH\QWLQKODWMXUD
ZKHQ DQWLRQ SRWHQWQDQJRNQRZQ WKDW JHQHULFRUG
FRQWDPLQDQWV SUHVHQW LQ DRXHFRKQWVWMOIQRQQLVQLWKHOLWHU
FRQWDFW ZLWK VXUIQFSHHQGKHEGVXWQDFM LQVGLVQLILFDQWHEUJUWV
VROLGFWV GHILQHG DV WKH UDWLKRH RD EWIRDXWQWLDPPSLQFDQWWRPLFJRD
FRQWDPLQDQW FRDQFHQWKLWQDQWVWLRDFWHLRQGRSWLRQV \$FFRUG
VROLGFVWQWDXPHLQDQW FRQFHQWKBWPLRMRUQWKRIPPHQGDWLRLQV
VXUURXQGLQJ DTXHRXWWRQOXWSRQLZKHFQDQKFKQDWLRQV SDUWLW
LV DW DQWVWLRDFWHLRQGRSWLRQDWLWVSHFLILF FRQ
FRHIILFLHQW YDQWHDWVWQGI EQRQVIRIOXWQH\H\VRZQWHLUDOGXH@R
LQ VLJQLILFDQW HULRUVWZKHHQFRASIGHMLRW\$HMGRI ERWKJHRORJLF
DEVROXWH LP SDFWV RI FRQWDFRQHOPDQDQWPEHJIDWLRQZRLWKLQWKL
VLWH VSHFLILF UPHGLDWLQRQHRSFMLVQV\PDHUDWVWQDQWVRI FRQ
FRHIILFLHQWVWQDQWVWLRQV DUVWSRQWLDODIVUDVJLWHLQ SRLQW LQ D JHRORJLF
FDOFXODWLRQV > @ FRQWDPLQDQW ZLOQHEQHVSIDWVW

JURXQGZDWHU DQG WKH KR V WL QHFRDXGLLQJDO E DPGDW Q XIP QVQ GR I W KH
D 3WUXH' PHDVXUHPHQW DW WKRDPMS Q ROLQWVBUHTXQLVLPYH QHVW RI WKH
UHPRYDO QH DF R QVRS KQHVKRQJOEG VXEMHFW PDWWHU WKH UHDGHU L
DQG DTXHRXV SKDVH WKLV P DAW KQHR WHDQI ZLQWQKBRHADQJOV
WR DFKLHYH ,M DMF KWMKURIE DHEB RFXPHQWV ZHEVLWHV
WKH FRQWDP LHWDQHND KDNQGQRMS
SRLQWV HQMDLWR QDPHQW WDDQV
PXVWXEHG WR SUHLQIDFWF RQWD
FRQFHQWUDWLRQV

7DEOH 9DOXHV IRU 8UDQLXP DV D)X
S+

.g P/ J
S+ 0LQLPXP 0D[LPXP

6RXUFH > 7DEOH @ 6HH DOVR UH
DQG SDJHV ±

:KLOH P DQ\ IDWH DQG UDQVS
DYDLODEOH IRU YDSUHLRXV PHG
PRGHOLQJ LV DQ DUHD RI DFW
GHEDWH RQ WKH SUREOHPV D
PRGHOV DQG OLWWOH FRQVH
UHDFWLRQV DQG UHDFWLRQ S
GHWHUPLQHG IRU ILHOG DSSO
,QWHUDJHQF\ 6WHHULQJ & RPP
(QYLURQPHQWDO ORGHOV ,6&
FRRUGLQDWLH IIIRUWV DP RQJ
XVH RU VXSSRUW WKH GHYHO
KGURORJLF DFOO JPHRGFHWDPLW R VLP
WKH WUDQVISBROVFBQDQWVWVPLQ WKH VKRXOG EH QRWHG WKDW LQIRU
VXEVXUIDFH HQYLURQPHQW

)DWH DQG WGBQVQRULW RI JUHDW
LPSRUWDQFBLIDQNLBQHQHWV DQG
FRQFHSWPRDGUNIWLUHG IRU UH
DQG FRQVLGRHWDQFHLDQFHLDQFH
DYDLOBHEHSHWWLVH LQ WKHLU XUDQLXP

6,7(6&5((1,1*)25 '(3/(7('
85\$1,80 &217\$0,1\$7,21

(3\$ KDV SXEOLVKHG VHYHUDO \$&RQHDFWLRQ FKHPLFDODQG WKH 6RLO 6FUHHQ
RQ WKH DSSUHRGDLFDWLRLQ URH PV LWWH [LFLW\ RU UDGLRORJLFDO ULVN
FRQWDPLQDWG DMMKU KDDQUGRDXV P

1. 'LVWULEXWLRQ RI 26:(5
3UHOLPLQDU\ 5HPHGLDWLRQ
6XSHUIXQG (OHFWURQLF & D
KWWS HSD JRY VXSHUIXQG
GI UDG SGI

6RLO 6FUHHQLQJ *XLGDQ
QG (GLWLRQ
SURYLGHV D PHWKRGGRORJL
EDVHG VLWH VSHFLILF VRL
66/

6RLO 6FUHHQLQJ *XLGDQ
7HFKQLFDO %DRFFNJKUHQRQW G(3\$
> @ DQG 6RLO 6F
*XLGDQFH IRU 5DGLRQXFOL
(3\$ 5 > @

(3\$ ZHEVLWH
KWWS ZZZ HSD JRY UDG
QLXP KWPO

,QYHQWRU\ RI 5DGLRORJL
IRU 6LWHV &RQWDPLQDWHG
0DWHULDQV (3\$ 5 6HH
7DEOH SDJH IRU DQDC
PHWKRGGRORJLHV DSSOLFDE
UDGLRQXFOLGH DQG 6HFW
RI ZDWHU VDPSOH SUHVHUY
LVVXHV

VLP
WKH VKRXOG EH QRWHG WKDW LQIRU
FKHPLFDO WR[BFLWD RDIQDQFH LQ
\$76'5 7R[LFRORJLFDO 3U@ILOH IRU
WVKRXOG DOVR EHDQRBXPHG WKDW
LQFOXGLQJ '8 LV ERWK D FKHPLFD
DO KD]DUG 66/V IRU '
FRQVLGHU ERWK W\SHV RI KD]DUG
6FUHHQLQJ *XLGDQFH IRU QRQ FD
FKHPLFDOV DQG WKH 6RLO 6FUHHQ
5DGLRQXFOLGHV 6LQFH WKH 66/
FRQFHQWUDWLRQ LWWVPIRVRXOG EH

6FUHHQLQJ *XLGDQFH IRU QRQ FD
FKHPLFDOV DQG WKH 6RLO 6FUHHQ
5DGLRQXFOLGHV 6LQFH WKH 66/
FRQFHQWUDWLRQ LWWVPIRVRXOG EH

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V X E V H F W L R Q V > @ + R Z H Y H U Q R
W K D W S D E B H F D R I V L J Q L I L F D Q W O \ U H
F K H P L F D U O G L Q R Q R J W R R I L E L W \

8UDQLXP DQG '8 FDQ EH GHW HFFKWDWQ@ FEW HPUHLD\W\WLFQDQDOWRJ DXQ G D PH
WKH GLIIHUHQW W\SHV RI UDGKD\WQRQP L&HD VHD \W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD
DQG RU JDPPD UDGLDWLRQ HPRUWWZHRGV L\WUHHV ZQDMWQ\W\WLFQD\W\WLFQD\W\WLFQD
YDVW FKRLFH RIRHQLXW &PHQJW V\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD
UDGLDWLRQ LV DYDLODEOH 5QD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD
\$SSHQGLRUD GHVFULSWLRQ RISVR\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD
VSHFLILF PHDVXUHPHQW WRRQO\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD
WHFKQLTXHV U\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD
0HDVPHQWV PDGH ZLWK ILHOGD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD
W\SLFDOD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD
PHDVXUHPHQW\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD
HQYLURQPHQWDO FKDUDFWHULFKVM\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD
FRPSRVLWLRQ\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD
QRW RU DUH RQO\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD
PXVW EH FROAHHFQW\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD
RUGHRE\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD
WKH FRQWDPLQDWLRQ VLWHVVR\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD
FRQWDPLQDWLG VRLO\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD\W\WLFQD

(3\$¶V 2IILFH RI 6,DOGLDRMUL \$ QUD QU H P H G L D O VLWX DWLRQ V FRQVLGH
FR POSHWHG D GUDIW FRPSHQGL XIPYRQ WR HUGHQDHWKUPD V GXVW ZLV
RI 5DGLRORJLFDO 0HWKRGRORSJRWWAQMRFDQDQJERLQFHR HD V D UHVXO
UDGLRQXFOLGHV OLNHO\ WR EH HIRGXQDQVSLQQDRLVLRQDQHGV\ QWHITQSH
DW FRQWDPLQDWHG VLWSOMWHKIHQH LGVRHLV QRW IDQFRQXGH DLU SRC
FDWDORJ RI HDWKDROGWORDDH\ LWDULWLFXODWHV IURP PXQLWLRQV
LQWHQGHG WR DQDWJLNUW \$UURM HIFQV VPKLV UHJDWURQ RWLHV VZRDWKB\$ L
XQGHUVWDQG WKLUH R R Q QMSAW VS XQIPWDHIVRI DQ\ 1DWLWRQDQWBWLRU
DQG OLPLWDWLRQ DRO\ QBLIZRXOODWPRFWRWHG ZLWK '8 FRQWDPLQD
UDGLRDFWL QHV BIQ YLDUFRSCOPHHV 'HSUDRIMHFGVLOHV
JXLGDQFHFRQPHQGDQ\ WDGDLQRDQ
SUDFWLFHV PD\ EH IRXQG LQ **F.1 Soil Technologies** LRQV RI WKH
0XOWL \$JHQF\ 5DGLRORJLFDO 6DQFHUDWLRQ FKEQRHQRGLHHMHQB\$HG II
\$QDWLFDO 3URWRFRQV QDQXDQVH\$B\$38 FRQWDPLQDQWBSVVRLOV
DQG WKH 0XOWL \$JHQF\ 5DGLDVLQFRQXGKUYH\ DQG 6LWH
QXUVWLUDWLRCQDQXPCQD\$5662

• ([FDYDWLRQ IGRLOVOSRRZMHDGOLRQ I VRLC
D ORZ OHYHO ZDDVQNGH UHSRVLWR

7.2 Groundwater Technologies

- 7 UHDWPHQW RI JURXQGZDWH5) F7F6QWBPQRQDWBRQHSLPQWWR
FRQYHQWL RQDO SXPS DQG WURHWDHW WPKHDWK RVGKH
 - 7 UHDWPHQW DRWJUW EORQEDR
SHUDERIOWULYHV EDQGLHU
 - (PHUJLQJ 3LO RDWQWXVG LHV WUH

3 XPS PQG 7 UHDW

3 XPS D Q G H W W K R Q W B H P R Y H F R Q W D P L Q D W H G
J U R X Q G Z D W H U I U R P W K H D T X L I H U D Q G F D Q E H X V H G W R

RI \$UYDGD & RORUDGR XVLQJLUDQIUDWVFRKUHSPWLFDHO@HGLDHQ LQJHV
= 70 IRU WUHDWPHQW RI ZHOQJIDWQHVKLQUPDQLXP UHWRQWLRQ L
FRQWDPLQDWG ZLWRKI XAUHQQLXPHYQI UHWRHRNQWV@HWRKRGV IRU VFUHH
PD[LPXP FRQWDPLQDW OHYHOU@LXP:5ZRXOG VKRZ WKDW WKH
FRQGXEWGVWKGLHV DW %UD] SWHOLXHQWODQGLW PD\ EH GLIILFXC
'RPHVWLFDWHULQH[LFRUDBQLQP IRXQGHQQLQJ LV HIIHFVLY
ORXQWDLQ DQWWDWLRQ 'LVWULM\WELQ]HG DV WKH SKRVSKDWH
& RQLIHU & RORUDGRXQ:@WHDQG WKH)R[5
& RPSDDQW & KHVGLQ 0DQRU LQ 'LQZLGGLMRUHPHGLDWLRQ
& RXQW\ 9L@JL,QLDHFV RI WKH\WW\GPHQLDWKRQWHDQWVWLRQ
PXQLFLSDO ZDWHU VXSSOLHUVHKHQGSZHDQWVWQDDWVXUDO DEVRS
FRQWDLQHG ZDWHU ZLWK FRQFRQWRQDMQWVR RMXHDLKRPVW JUR
LQ H[FHVV RI WKH 0&/V :57 SUDRQYLQPHQJSLQJRWUDWKHU WKDQ HVW
VFDOH DSSUR[LPDWHO\ RQH JDRQWURQPSHGLDPWLRQH8SDQDGNH RI XU
ODUJHU VFDQH LQXWORQMW\SPFDOO@V\BQ\H YHU
XVLQJ WDPHGLD WR GHPHQVWSUDWHRQWLRQ RMXQD QKQIORZHU
HIIHFVLYHQHWR/QRMV SWKRMVW\SHQDQH VJH QH(anthus) KDV EPIHQVWHDWHG ZLW
GHVLJQ SDUDPHWHUV IRU WKHUURQDXPFZOMWWDWHRQW
GRFXPHQW WKH HIIHFVLYM\WP\WP\QSRQSZFRQWDXPLQDQWVHPGQHDU
DQ\BHHW UHJXROB\W\RDQFQWVHTX\KHP\Q\EFQHDUSRZHSQDQWV
,Q HDFK FDVHLWWRH SODORWUXQDQH\LAQHW\W\H P3KG LDWLRQ XVLQJ
VXF\HOO\ PHW JURVV DOSKD DQG WUDQW\JURV RI '8 FRQWDPLQDW
FRSOLDQFH DW DOO WLPHV DW DILULQJUDQJH DW WKH \$EHUC
*URXQG LQ 0DU\ODQG KDV DOVR E
7.3 Technologies for Soil and Water > @ WSKUHPHGLDWLRQ RI XUDQLXP
6HYHUDORW\HFKQFDQ EH XVHG WDFRUB\W\KHMURXJK WKH SUR
VRLO RU JURXQGZDWHU ([DPS\KJ\YRLQFW\W\LRQ LQ ZKLFK SODQ
FRQFHQWUDWH DQG SLUQHDFQW\W\WDW
• ,Q VLWX VWDELOL]DWLRQ WIKURPXYKUWRFHXRH@URXQHGZDWHU >
DPHQGPHQWV JURXWLQJ R\RFQDFSHQW\W\DWLRQ RI XUDQLXP FRQ
FRQWDPLQDWG VRLO DQG UHPRYHGWKUR\RLQ E\ WKH SODQW
WKH YRROIXPDWHULDO WKDW RWKHU
• 3KWRUHPHGLDWLRQ LQ ZKLFK\H\GDEQW\W\H\H\B\U GLVS
WR H[WUDQW\QFRV\W\U\RRU JURXQDWHU \$ UHTXQWHRM\W\H\PHGLDWLRQ LV W
SURSH\W\DGQ\W\SSRS\W\RD\EFK\B\GRSWHG IR
W\KHF\W\Q\W\H\PHGLDWLRQ EHDULQJ SODQ
,Q VLWX VWDEHQW\W\H\PHGLDWLRQ EHDULQJ SODQ
PHWKRGV DUHL\W\H\PHGLDWLRQ EHDULQJ SODQ
FRQW\W\DWLRQ LQXQ\W\H\PHGLDWLRQ EHDULQJ SODQ
7KH DGG\W\H\PHGLDWLRQ EHDULQJ SODQ
SKRVSKDWH VROXWLPRQV\W\H\PHGLDWLRQ EHDULQJ SODQ
DQG XQ\W\H\PHGLDWLRQ EHDULQJ SODQ
UHODWLYHO\ L\QPV\W\H\PHGLDWLRQ EHDULQJ SODQ
> @ > @ *URXWLQJ RU FDS\W\H\PHGLDWLRQ EHDULQJ SODQ
FRQWDPLQDW\W\H\PHGLDWLRQ EHDULQJ SODQ
XVHG WR VWDELOL]H XUDQLXP R\W\H\PHGLDWLRQ EHDULQJ SODQ
> @ \$V ZLWK SHUPHDEOH UH\W\H\PHGLDWLRQ EHDULQJ SODQ
VWDELOL]DWLRQ\W\H\PHGLDWLRQ EHDULQJ SODQ
3UHFLSLWDWLRQ RI XUDQLXP R\W\H\PHGLDWLRQ EHDULQJ SODQ
OHDYHV XUDQLXP KLJKO\ LQVROXEON DQG HVVHQWLDOO\

7.3 Technologies for Soil and Water

6HYHUDORW\HFKQFDQ EH XVHG WDFRUB\W\KHMURXJK WKH SUR
VRLO RU JURXQGZDWHU ([DPS\KJ\YRLQFW\W\LRQ LQ ZKLFK SODQ
FRQFHQWUDWH DQG SLUQHDFQW\W\WDW
• ,Q VLWX VWDELOL]DWLRQ WIKURPXYKUWRFHXRH@URXQHGZDWHU >
DPHQGPHQWV JURXWLQJ R\RFQDFSHQW\W\DWLRQ RI XUDQLXP FRQ
FRQWDPLQDWG VRLO DQG UHPRYHGWKUR\RLQ E\ WKH SODQW
WKH YRROIXPDWHULDO WKDW RWKHU
• 3KWRUHPHGLDWLRQ LQ ZKLFK\H\GDEQW\W\H\H\B\U GLVS
WR H[WUDQW\QFRV\W\U\RRU JURXQDWHU \$ UHTXQWHRM\W\H\PHGLDWLRQ LV W
SURSH\W\DGQ\W\SSRS\W\RD\EFK\B\GRSWHG IR
W\KHF\W\Q\W\H\PHGLDWLRQ EHDULQJ SODQ
,Q VLWX VWDEHQW\W\H\PHGLDWLRQ EHDULQJ SODQ
PHWKRGV DUHL\W\H\PHGLDWLRQ EHDULQJ SODQ
FRQW\W\DWLRQ LQXQ\W\H\PHGLDWLRQ EHDULQJ SODQ
7KH DGG\W\H\PHGLDWLRQ EHDULQJ SODQ
SKRVSKDWH VROXWLPRQV\W\H\PHGLDWLRQ EHDULQJ SODQ
DQG XQ\W\H\PHGLDWLRQ EHDULQJ SODQ
UHODWLYHO\ L\QPV\W\H\PHGLDWLRQ EHDULQJ SODQ
> @ > @ *URXWLQJ RU FDS\W\H\PHGLDWLRQ EHDULQJ SODQ
FRQWDPLQDW\W\H\PHGLDWLRQ EHDULQJ SODQ
XVHG WR VWDELOL]H XUDQLXP R\W\H\PHGLDWLRQ EHDULQJ SODQ
> @ \$V ZLWK SHUPHDEOH UH\W\H\PHGLDWLRQ EHDULQJ SODQ
VWDELOL]DWLRQ\W\H\PHGLDWLRQ EHDULQJ SODQ
3UHFLSLWDWLRQ RI XUDQLXP R\W\H\PHGLDWLRQ EHDULQJ SODQ
OHDYHV XUDQLXP KLJKO\ LQVROXEON DQG HVVHQWLDOO\

RI FRQWDPLQDQW SOXPHV DQGU&WRQHF @ QJ6LWH VSHFLILF IDF
JURXQGZDWHU DQG RWKHU HQM WRDQERQH QWIDQJ UWHKVR XDUFVHVD O FOHD

01\$ UHIHUV WR WKH UHOLDQF **8.2 For Ad** WXUDO
DWWHQXDWL RLQGSLQRJFBI YDQHULHWBQGHU WKH & \$ (3\$ HVWDEOLVKH
SKLFDO FKHPLFDO RU ELRORJLWDDQDLSHBLERWDSH MPKXARRH RVR DQ
DFKLHYHS HWEWHS LUDHPLRQ REMHFLQIGYLYVGXDO QRW WR H[FHHG PL
ZLWKLQRDQ DHEOH WLPHIUDPH FRPSIWUDUHGUWR @
RWKHU PWRHWHKRGV , Q RUGHU IRU QDWXUDO
DWWHQX B WLRHOO HF H G DV D U **8.3 For Water**
GHWHUPLQLQJDWQGHQH QW WR WKH 6':\$ (3\$ HVW
VWDELOLW\ DQG LUUHYHUL ELOQWVRI RILWURHVB PRVHS/KDQULWPHU
LV SRUWDQW WR VKRQ\WLDW DXODSUXHPHQ GULQNLQJ ZDWHU >
VXIILFLSHQWMORWLYH \$GGLWLRLQDOO\ VLWH
VSHFLILF GHWHUPLQDWWLRQEVHZ **8.4 Storage of Depleted Uranium**
PDGH WR HQVXUH WKDW VRUSWLRQ QW DWURG VKSHO\ DURXQ
VXEVXUIDFH LV VXISLRWHFWV LVRDMLRUXLQ\ RI WKH LQYHQWRU\ RI
KXPDQ KHDOWK DQG WKH HQYLSQRLPHQMW DWWHV (QULFKP HQW &
VLWHV RU DW '2(VLKHHPLQIBWDWURU
(3\$ 67\$1'\$5'6 \$33/, & \$%/(LV RQO\ D IUDFWLRQ RI WKH WRWD
72 '(3/(7(' 85\$1,80 6,7(6 WKDW XQPHU (QKJWJSWSFW \$(\$ WK
VWRUDJH RI GHSOHWG XUDQLXP
:KHQ FRQWDPLQDWHG VLWHV W'RSEHUVHGDWHDWHG E\ WKH
SXEOLF XVH DUH WIRHEM (BSPHGDPDWAGVMRPHG LQ WKH IRUP RI X
PHGLD VSHANIEFDVHG VWDQGDUGVDRQJXFRULWHDWHG LV D FRORUOHV
VHYHUDWLBQWGHUQYHHLGLDRAULRVQHPHQFXODUZHLJKWLHQWROLG
QHHG WR EH FRQVLGHUHIS 9DWLRPXS/HVWWWWWWWWWWWWWWWWWWWWWWWWWW
GLIIHUhQW DV SHGLWDWIRRQWKSUHBLQHWWWWWWWWWWWWWWWWWWWWWWWWWW
7DEOH OIMRUVWWKDHWRWHV WKDW PDSSHUQWXRPH DQRYLQWGR ED\OL
YDULRXV PHGLD WKDWHRDWERQFLQHWRQWLRQ WLRQHSUDHWXWHD HD EDQGH
GXULQJ UHPHGLDWLRQ 7KH IROORWBRQHUV&DQGQV DOKURHH SKDV
SURYLGH IXUWKHU GHWKIRIXQG RMWOKG GQUTXHUV DQG JDV FRH[LVW
EH QRWHG WKDW WKH GLVFXVVLRQ SUHVHQWHG KHUH LV QRW
LQWHQGHG WR EH FRPSUHKHQ \$LYH MRLQHSPWUHREUJQDQWLRQ
D VWDUWLQJ SRLQW IRU IXUWKFRQQLQPHFV&RQSMHPRMORRS PDHQW
2(& 1XFODISJHQDUGI WKH
7DEOH 0DLQ 6WDWXWHV \$SSO\LQJ WQWBLULQDWLRQ BQJ\$V\$QIRQF\ R
LQ WKH 5HPHGLDWLRQ 3URFHVV 0DQDJHPHQW RI 'IPSCORHWHG V8KIDQWLX
0HGLD 6WDWXWH '8DULVLQWKRURPSHUDWHRQW RI HQ
\$LU & \$\$ SODQWV FDQ EH VDIHO\ VWRUHG L
:DWHU 6':\$ LQFOXGLQJ XUDQLXP WHWUDIOXRU
6RLO &(5&/ \$ 5&5\$ XUDQLXP RQLCBVDQG 8LQ FRDWHD
:DVWH 15& UHJXODWLRQV 2LQHUV VWHHO FRQWDLQHUV LQ H[WHUQDQ

FRQWDFW ZLWK VWDQGLQJ ZDWHU
FRQWDLQHUV DUH URXWLQHO\ LQV
GHIHFWV QHDGLQJ WR FRUURVLRQ

8.1 For Soil

8QGHU &(5&/ \$ 5&5\$ (3\$ V VLWH FOHDQX
VWDQGDUGV OLPLW D SHUVRQ V LQFUHDVHG FKDQFH RI
GHYHORSLQJ FDQFHU WR EH WZHQQ LQ DQG
LQ WUDQG XUDQLXP RQ WKH

8.5 For Disposal

6 X E V W D Q F H V 3 R C J O H X Q F I L R 3 Q Q & Q Q W & 3
) R U S X U S R V H V R I G L V S R V D O ' G K L H Q F I R Q S / Q I G F H D U E H Q H D R U U H O H Y D Q W
O R Z O H Y H O Z D V W H //: D Q G L W M T G X L L U S H R P V H D Q W / V \$ 5 \$ 5 V D U H Q R W
V X E M H F W W R & X O D W R Q H D & R P S P L Q / R M V R V Q X I I \$ B R H M Q M & Q H D Q X S V K R X O G
15 & U H J X O D W U R Q S V L D Q Q H D S (2 U H Q H U D D F O Q H Y H I D U L O V H N D W R K L Q W K H
' L V S R V D O R I ' 8 P L [H G Z D V W H W R Y L F Q D U E R Q / R J B Q L F U L V H N U D Q J H E
U D G L R D F S W R L Q H I Q F A R D Q G D 5 & 5 \$ K D H J D V U R G Q D X E O H P D [L P X P H [S R V X U H I
Z D V W P I S R I Q P H Q W W P E X H S H U I R U P H G L Q F D O F X O D W L Q J F O H D Q X S O H Y H O
F R P S O L D Q F H Z L W K 15 & //: U H T H I L S U R - M P X H Q H W V I D Q P G D O O D S Q G W H Q W L D C
5 & 5 \$ K D] D U G R X V Z D V W H U H T X L W M P R I Q J K V D O O P J H U G R L D Q G H Z D W H V L O
V X U I D H H U Z D M G I U P H / Q W U X B W X U H V H W
7 K H ([H F X W L Y H 6 X P P D U \ R I W K B V V L V D A L V L K G J H D O F X O D W L Q J U L V N
1 D W L R Q D O / D E R H D W R D e r f e r t e d 6 X S H U I X Q G U D G L R Q X F O L G H S U H O L
D U D i s p o s a l F o r m s S X L E V O K H Q Q H Q - X J R D O 35 * F D O F X O D W R U 35 * V I R U
Q R W H G W K D W W H Q W W K M D R I R X B W P S S U R J U D P V D U H U L V N E D V H G F R Q F I
' 8 P H W D O ' 8 2) D Q G 2 8 L Q W K L V I U R P V W D Q G D U G L J H L Q I H Q J K D W L R Q V
V W X G I V K R X O G E H D F F H S W D E O H [S R U X Q H D L Q M R X W P D A H L R Q D V V X P S W
G L V S R W D O V D W F H W L D H Y W Q D 7 H V W W R M A L W \ G D W D 7 K W R B H H F R Q V L G
176 D Q G (Q Y L U R F D U H ' > @ S U V R W X I F W K M H D R G B M A X P O D Z Q W V W K R X J K
W K D W 3 7 K H ' B U S H U R R Q & I M G / H U H G D W S Q C E L H F D E O H W R D S D U W L F X O D U V
O R Z O H Y H O Z D V W H X L Q / G B I Q G E R W D K G G U H R V U G A R Q K & B S Q L Q H D V O W X F K D
15 & W X H O D W L R Q V ' , W L Q G L F D W H F G R Q V K J H D F S D M V N A P S H Q F X H V H G I R U V L W
I R U G L V S R V D O D W 3 W K H 176 V F U H D B Q H Q R I D Q G X Q L T Q I H W L D O F O I
J H R K \ G B R D Q Q R G J L L Q Q W O W X H W W L Q J D S S Q I K H D E O H 35 * V F D U H D Q Q R S W D F W X
V W X G I D O V R Q R W H Q P W B D D W 3 (D F V K D ' Q G R U G V R D E Q H G D V S K S R O X L O H G G Q V V X F H
G H J U H H R I X Q B I S U Q D L Q V \ U H J D K H L U U R O H L Q V L W H V F U H H Q L Q J
D Q G 2 8 D F F H S W D E L O L W \ > I R U G D W I S R V D B R Q W D 1 P 7 L 6 Q Q D Q W V G R D Q Q R W R Q
Z L W K W K H X Q F H U W D L Q W \ G H F W H H D T X L Q J H U Q U W K M H I R Q H G M U D Q S D M W M L H
R U G H U ' 8 P H W D O D Q G 2 ' 8 > @ V L W H \$ G G L W F L R X Q Q G Q E H X A K H H G W R
H V W D E O L V K I L Q D O F O H D Q X S O H Y H
(3 \$ K D V L V V X H G J X L G D Q F H H Q W U R S H H G H Y D O X D W L R Q S W D N H Q M G S O D I
3 (V W D E O L V K P H Q W R I & O H D Q X S S / H R J H D V P I R W K & M V & A \$ D O X D W L R Q L V F
6 L W H V Z L W M H S D R Q L V R D F I M Q L D W L R Q W K H Q L Q H F U L W H H D L H D F V R L U R Q H P R X H G Q L
26: (5 1 R \$ X J X V W W K H 1 D W L R Q D O 2 L D V D Q D Q F B Y D U G R X
Z K L F K S U R Y L G H G F O D U L I L F D W B R Q Q R W L H R Q W B Q D Q Q L Q S Q H Q F 2 Q F H W K H
S U R W H F W L Y H F O H D Q X S O H Y H O Q L Q R H U F U D L Q W H R U D F D B Y H D C V W K H V 5 F * R P
F R Q W D P L Q D W L R Q D W & (5 & / \$ V I E M H U / H W R Q H Q P R E G I D V Q H F A V E R D U V H G R Q V
U H L W H U D W H G W K D W F O H D Q X S W S R H F U L D W G P L D R V Q I X F Q O L G H M R D U W R E H F R P
J R Y H U Q H G E \ W K H U L V N U D Q J H H V R M D B Q I O V K B G F D Q R D J H Q A D Q X S V W D
H V W D E Q W K H H G D W L R Q D O 2 L O D Q G + D] D U G R X V

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\$5\$5 \$SSOLFDEO BD ORGU \$\$SHSOHRYEDKQH DWDWH
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& \$\$ LU \$FOMDQ \$
& (5 & / \$ & RSUHKHQVLQIRH QWSDBR 5HVS & QVDWLRLQ DQG /LDELOLW\
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'8 'HSOHWHG 8UDQLXP
(3\$ 8 6 (QYLURQPHQWDO 3URWHFWLRQ \$JHQF\
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//: /RZ /HYHO :DVWH
0\$5/\$3 0XOWL \$JHQF\ \$DGER \$Q DWDWV R3FUROV
0\$566,0 0XOWL \$JHQF\ X6EY GLOOGW, BORYAH & WLJDWLRLQ 0DQXDO
0&/ P & RQ DWD P KQ DQW /HYHO
01\$ DWDWV XQUDWV \$WQVH I Q XDWLRLQ
1&3 1DWLRQDO 2LQ EDVQNCB RQ DWDWV GLRRQV 86QDWLQJ H Q F
15& H J KXOFDOWHDLW & R PPLVVLRLQ
176 HV WH & DVGLB 7
2(&' 2UJDQL]DWLRQ IRU (DWDQGR PHLYFH DWDWV SHQDWLRLQ
26& 2Q 6FHQH & RRUGLQDWWRUV
26:(5 2IILFH RI 6ROLG :DVWH DQG (PHUJHQF\ 5HVSRQVH
35* LQD QUBIOPRGLDWLRQ *RDO
5&5\$ 5HVRXUFH & RQVHUYDWLRQ DQG 5HFRYHU\ \$FW
5)(76 5RFN\)ODWV (QYLURQPHQWDO 7HFKQRORJ\ 6LWH
530 UR M5HHPW GOLDDQDQD BHUV
6':\$ 6DIH 'ULQNLQJ :DWHU \$FW
6*6 6HJHPQWHG *DWH 6\VWHP
66/ 6RLO 6FUHHQLQJ /HYHOV
7', 7ROHUEOH 'DLO\ , QWDNH
86(& WDWHB\Q LQWHLGF KPHQW & RUSRUDWLRLQ
:+2 :RUOG +HDOWK 2UJDQL]DWLRQ
:57 :DWHU 5HPHGLDWLRQ 7HFKQRORJ\ //&

* ORVVDU\

Alpha particle – \$ S R V L W L Y H O \ F K D U J H W G Z B S D Q H W K I W F O R H Q P / D D G Q I G X W Z R R I S U R W R C F H U W D L Q U D G L R D F W L Y H Q X F O G I L E \ \$ V X S I Q D O S D D H M A L F R O H O / L F D V Q E B I W H H R I S D S H U D Q G S R V H Q R G L H B F M W H R R U Z H M M H U Q M D K H U V D D G Q D S V R I V R H Q D W K H U L Q J H V W H G R U L Q K D O H G

Becquerel (Bq) – 7 K H D Q Q W L H R U Q , D Q Q B W M G S W X R J I P H U D V G L R I D X D V Q Y M R V R D Q H R V Q U D Q V I R U G L V L Q W H J U D W L R Q S H U L W I H S F U R H Q / G H G 2 I M Q H Q D M D Q R G X M R D Q C M V L O M N H P L O O L R Q V 0 % T R I % H F T X M H U D H G Q W L R 2 Q D H O & E R W H Y M W K H X Q L V O O L L R / Q H T X % T

Beta particle – \$ Q H O H F W U R Q R U S R V L @ W I U R D Q F W I P M W V Q H K G O E H L F H % M D W D Q S D U V W R S S H G E \ D O X P L Q X P 7 K H \ F D Q S R V H D V H U L R X V G L U H F W R U V H U L R X V L Q W H U Q D O U D G L D W L R Q W K U H D W L I L Q K D O H G R U L Q J H V

Curie (Ci) – \$ W U D G L W L R R P D H O D X Q U R H D P M M E D Q W X U L H H T X D O R I W K D W T X D Q W U D G L R D B F W H M H D O L Q Z K L F I Q X M K O H H D H U D W M D Q V I R U P D W L R Q V S H U V H F J U D P R I U D G L X P L V D S S U R [L P D W H O \ & L

Depleted uranium – 8 U D Q E R Q W D L Q L Q J O H V V W K H D O R P Q W X I B Q Q W X R D O X U D Q L X I P E O V R S Q U D Q K X P

Enriched uranium – 8 U D Q L Q P Z K L F K W R K H R S I U M R S I R U L W R W R S H X U D Q L X P K D V 6 H H D O V R G H S O H W H G X U D Q L X P

Gamma rays – + L J K H Q H O U R D Q H R V L F U D L G H Q W H L R Q D H P Q U D G L R Q X F O L G H V Z K W U D Q V L W L K R L Q J K D H Q R V Z R I U V H M Q H M H V K D Y H K L J D Q Q H D U V K R U W Z D Y H O H G * D P P D U D \ V D U H Y H U \ V L P L O D U W R ; U D \ V

Half-life – 7 K H W L P H L Q Z K L F K R Q H U B Q D R D R A W M K H D W R R W R S H G L V L Q W H J Q X F O H D U I R U P + D O I O L Y H V Y D U \ I U R P E L O O L R Q W K V R I D E L O O L S K \ V L F D O R U U D G L R O R J L F D O K D O I O L I H

Ion – \$ Q D W R R O R E X D H W K D W K D Z M O R H R F F W D Q R Q R U F W D R X R V U Q J L W W R K D Y D Q G W K H U H I R U H E H F K H P L F D O O \ D F W L Y H

Isotope – \$ Q X F O L B B H P I H D Q Q V K D Y L Q E H W S R U H R W D R F G H M D X P A E M D Q I X Q H X W U R Q V

Maximum contaminant level (MCL) ± 7 K H R D Q W R I D D Q R M Q W K E P H W S R H V H Q W L Q G U L Q Z D W H U X Q G H U W K H 6 D I H ' U L Q M K L H Q V W D D Q I G D U G W W W Q B X W Q W I H Q N L Q J Z P X V W P H H W

Microcurie (μ Ci) ± 2 Q H P L O O L R Q W K R G L D V L Q W M H H U D W I R Q V S H U V H F R Q G

Molecule ± \$ F R P E L Q D W L R Q R I W Z R R U P R U H D W R P V W K D W D U H F K H P X Q L W R I D F R P S R X Q G W Q G W H F D Q L I Q [I D V O V E R I I L W W W H D K H D P L F D O S U R S H

Monitoring ± 7 K H X M D S P R Q J D Q G G H W M Q F M V W M D Q W H P M K I S P O H Y H C R W R H W D G L D W R [I D M U I P D D Q O D R Q G Z D D W H U

Millirem (mrem) ± 2 Q H W K R X V D Q G W K R I D U H P

Neutron ± \$ P D V O O S I S B R W V F V L Q J K O R U J H D M R S V L F L D F O O V F R X Q F G O E K W K L S Q D Q Q H X W D R Q D B R X D P D D V B V S R Q

Nuclide ± \$ J H Q H D S S O W F D I P P H F W R R U P O O P B H O V R I 1 X F O L G H V D U H F K D U D P Q X P E H U R I S U R W R Q V D Q G Q H X W U R Q V L Q W K H Q X F Z O H V V K L Q D W K Z H H O C D W R P

Oxide ± \$ F S R R P X Q G I R U P K H G U E H B F \ W H Q Q Z I R M U K H D Q H R P M H Q H A S O H R W X V D P I H U U R [L G H L V L U R Q W K D W K D V F R P E L Q H G Z L W K R [\ J H Q

Picocurie (pCi) ± 2 Q H B Q Q L R D W F K U R F X U L H G L V L Q W H J U D W L R Q V S H U V H F R Q

Proton ± \$ V P D O O W S S I U P V B L O F O O H Z L D W K R R Q D Q X F O H X V W K D W S R V V H V V H V F K D U J H B I K U R Q X B U R W R Q V L V P I X F Q D I E T H O V R U H D F K F K H

Rad ± 6 H H 5 D G L D W L R Q \$ E V R U E H G ' R V H

Radioactive decay ± 7 B H R F H V V L Q Z K L F K D N Q Y H Q F O P H E V O H D G D D G W R B Q D Q G F W R R D H D V E W H Q X F O O E P X M R I G L U M M U F H Q H W S D Q E H H P L W W H G E \ G H F D \ D O S K D E H W D D Q G J D P P D S D U W L F O H V

Radioactivity ± 7 B H R F H V V R I X Q G H U J R L Q J V S R Q W D Q H R X V W U D Q V I R U P D H P L V V L R Q R I D O S K D R U E H W D S D U W L F O H V R I W H Q D F F R P S D Q L H G

Radioisotope ± \$ Q L V R W R P S H V R W K D Q W V Q Q D E Q H Q X F O H X V 5 D G L R D F W L Y H F R P R Q O X V G L Q V E Q I S Q E V / G P H G H F Q Q H O H K V W H Y D I Q P H M D V D D E C E H I U Q X P R I S U R W R Q V D Q G Q H X W U R Q D F W K L V R I X Q K F R D Q M R S S R U R H L B D V I H O \ D U W L I L F L D O U D G L R L V R W R S H V K D Y H E H H Q L G H Q W L I L H G

Radionuclide ± \$ Q X Q H V W R B U E P F Q Q L G H

Rem ± 6 H H 5 R H Q L W D H Q H Q T W 0 D Q

Roentgen Absorbed Dose (rad) ± \$ E D V L F X Q L W R I D E V R U E H G U D G M D K V H L R Q G R V ³ J U D V Z K L F K L V M T M X R U Y D Q H Q U T D G O V W K H G R V H G H O L Y H U H V G R M R D Q H Q H U S J H D P R U P D W H U L D O

Radiation Equivalent Man (rem) ± \$ X Q L W D R I H Q T W G Y R V H 5 H P U H O D W H V W K H D E W L V V X H W R W K H H I I H F W L Y H B Q R O R R J W F D O O G D D G J L D V R I L R M Q K H D U D V W K D I V H Y H Q I R U W K H V D P H D P R X Q W R I D E V R U E H G G R V H

Specific activity ± 7 K H D R W U D L Q M S R H L S R W X Q P V W B H D U V L H I R W K D H U D L Q Z K L F K U D G L R L R V F F W B S H R R Q V L E V R I Q Q D V R R S V R W

Treatment – \$ μ W U H D W P H Q P M P D Q M E K Q R S H R W D / M U R Q V R I X Q D V W D R O S M H U D V W W R F R S R V L R M L R Q D] D U G R X V V X E V Q D Q P H Q D Q Q O W K U D R Q V V R B F O K V H R F L D F S D K O E P H D Q V V R D V W R U H G X F H W R I L W F K M V F R P Q R V E D E L Q D W R H U G Y P R D O X H P U H L D O E \$ S S H Q G L [I R U F R P S O H W H G H I L Q L W L R Q

Uranium ± \$ QDWXUDOORFFXUULQJ UDGLRDFWLYH HOHPHQW ZKRVH
XUDQLXP 1DWXUDO XUDQLXP LV D KDUG VLPOYQHUVHZDIPVRNQMKL
XUDQLXP

X-rays ± +KLHQHWHFHWRPDJQHLWWVAFHDQWGRHDQVLRQHFLWQDKLWIRP
HQHWJKHOO WR D VOKRHOU ~~WVKRQHOUJKLUQ\HQHUJ\~~ DQG D VKRUW ZDYH C
YHUVLIDDU WR JDPPD UD\V

\$ GGLWLRQDO 6RXUFHV RI , QIRUPDWLRQ
7KH IROORZLQJ UHSRUW\ VGRIFKUH DQG WIDQ Q DZHEQLRUPDWLRQ DE
\$UJRQQH 1DWLRQDO /DERUDWRU\ *Depleted Uranium Health Fact Sheet*
\$UJRQQH 1DWLRQDO /DERUDWRU\ 'HSOHWHG 8) 0DQDJPHQW , Q
KWWS ZHE HDG DQO JRY XUDQLXP
, QWHUQDWLRQDO \$WR PLF (QDQW\ \$JHDQW\ 6KHHSHQHWQW H8QDWLRQ
\$JHQF\ , QIRUPDWLRQ 6HULHV 'LYLVLRLQ RI 3XEOLF , QIRUPDWLRQ
1RUWK \$WODQWLW\ 7UHDW\ 2UJDQL]DWLRQ 1\$72 , QIRUPDWLRQ 'H
KWWS ZZZ QDWR LQW GX KRPH KWP
7KH 5R\DO 6RFLHW\ 7KH +HDOWK +DJDUGV RI 'HSOHWHG 8UDQLX
\$YDL QDWR LQW GX KRPH KWP
8 6 'HSDUWPHQW RI 'HIHQVH 'HSOHSRPHQW CHDSOKP BQSNORLUWM RW
8 6 'HSDUWPHQW RI (QHUUHQ\ DLOFHO DRQDQHYPLH QRQQ'HSOHWHG 8UD
0DQDJPHQW *Depleted Uranium Hexafluoride Fact Sheet* : DVKLQJWRQ '&)DOO
8 6 'HSDUWPHQW RI (QHUU\ 2IILFH RI (QYLUR QPHQWD O 0DQ
'HYH DQO JRY XUDQLXP *Depleted Uranium: A DOE Management Challenge* : DVKLQJ&W RQWREHU
8 6 'HSDUWPHQW WIRIF HQRIIU JXUFQHBLHQQFH \DQGDQDFRQWOLB
(QYLURQPHQWDO DF, W\ \$QW\ WIRIJ \$QWDH\ WQDQH\ WYHR\ WWDKQHDJRHQH\ QMU\ BQG 8VH
'HSOHWHG 8UDQLXP +H[DIOXRULGH \$SULO
KWWS ZHE HDG DQO JRY XUDQLXP *QHSDFRPS*
8 6 (QYLURQPHQWD O BAURW\ WIRIF HQRIIU \$JHQF\
KWWS ZZZ HSD JRY VXSHUIXQG UHVRXUFHV UDGLDWLRQ SGI XU
8 6 (QYLURQPHQWD O 3URW\ WIRIF QRIQ* \$QW\ DQF H6RLO 56FGLRQXFOLGH
%DFNJURXQG 'RFXPHQW 2QIGRUR \$L5UDG(3\$WLRQ DQG , 26:(5 'LUHF
2FWR KWWS ZZZ HSD JRY VXSHUIXQG UHVRXUFHV UDGL
8 6 (QYLURQPHQWD O 3URW\ HFWRQ \$JHQF\ 6RLO 6FUHHQLQJ *XL
2FWREHU
8 6 (QYLURQPHQWD O 3URW\ HFWRQ \$JHQF\ &RPPRQ 5DGLRQXFOL
XO KWWS ZJZRY HSXDS HUIXQG UDHW\ WIRIF QHSDFRPS SGI
8 6 (QYLURQPHQWD O 3URW\ WIRIF QHRIIF HJLPHDGE OHPRQDFWLYH
'LVVROYHG 8UDQLXP IURP *URXQGZDWHU)U\ &DQ\RQ 8WDK 6HS
, QWHULP 5HSRUW \$LU DQGIV5\$RGQDHWLRS\$ (PH&JHQF 1RYHPEHU
:RUOG +HDOWK 2UJDQL]DWBRWQH FWHISRDQVRIP WQWDRXQH
Source, Exposure, and Health Effects *HQHYD \$SULO
1XFOHDU (QHUU\ \$JHQF\ 2UJDQL]DWLRQ IRU (FRQ RPLF &RRSHU
5HPHGLDWLRQ3RRCQBXQHLSVWLRMLVQHSRUKW E\& 1(\$ DQG WKH , QWHU
\$WPRF (QH\$UHQF\\$ (\$
1DWLRQDO 5HVHDUFK&RXXQFLQHQHYD GRXUDV\ ISRQ XUH 3WV

\$SSHQGLT 7HFKQLFDO %DFNJURXQG RQ 8UDQLXLP DQG

2ULJLQ DQG +LVWRU\

\$IWHU WKH GLVFRYHU\ RI I\WRV SRQG K\WHD\ VSUDI D\OL FHDQ VPKDWWDU
LVRWRSSHZRRIXOG KDYH WR EH VHSDUDWHG BUIRVRWKRSHHPX,QK WRUH
6WDWHV PDVVLYH HIRUWVWZKHU\IDQQRQHWWDDQNBIGRNDFNSDUWRRSURG
8

(Q U L F K P H Q W L D / W D L S Q F R J F I H D W H V R K O / K H L V D R P V R R S Q H W U R H O D W L Y H W R D Q R W H
H Q U L F K P H Q W P H W K R G O X D W L J O H L J T H G Q R V M W U I B D Y Q L R X 8 P X D D Q L J X H P Q B H S W H W H
Z D V W H S U R G X F W 7 K L V Z D V W H E H F D P H N Q R Z Q D V G H S O H W H G X U

3 URGXFWRQ RI KLJKO\ HQULFKH G XWLRD Q\ KXHP G H F\ HHDQV G\ GQIHLQH G V F
SURJUDQ WKH 8QLM\ W\G F\ K\ P\ D\ V\ S\ A\ V\ D\ V\ R\ H\ K\ Q\ Q\ W\ S\ E\ I\ R\ W\ K\ W\ SURGXFWLR
RI ORZ HQULFKH G XIR\ D\ QFLR\ P\ D\ OH\ Q XUFR\ D\ R\ D\ J\ U\ I\ X\ H\ O\ \$ V\ D\ K\ P\ H\ W\ K\ O\ W\ R\ I\ S\ D\
DFWLYLWLHV '2(FXUUHQWO\ P\ B\ L\ Q\ P\ R\ D\ V\ W\ Q\ R\ I\ D\ L\ W\ D\ V\ W\ R\ U\ L\ Q\ G\ H\ Q\ W\ R\ K\ H\ K\ H\ [DIOXRULGH 6 PDOOHU TIX\ Q\ K\ W\ L\ R\ R\ I\ U\ D\ P\ V\ DRQ\ L\ X\ PD\ B\ H\ W\ D\ V\ R\ UXHGD\ Q\ L\ X\ P
DQG XUDQLXP R\ LGHV

8VHV RI 'HSOHWG 8UDQLXP

7KH PRVW ZHOO NQRZQ XVH YIRU '8 LV LQ WKH PDQXIDFWXUH RI
GHQVLWURDSOKRSLF SURSHUWRUVRWKMULVPDQOLWIRDXWHSQUSRVHVWRU
FRQYHQWLQRQDO PXQLWLRQV HYDQHQVDISQEEQDQWLQQXVDUHQDQRQRQ
PLVVLOHV UDFLQJVVDLOERDWQNKHRNOSVLWDDQGVDRUDVRQDWQGLQOXBQ
IURP HTXLSPHQWXVHGIRHQRDZGDQWUQWKKHUQGSVFXVVLRQVRIV

Further Enrichment

'8 ZDV RQFH SURSRVHG DV D I H G V W R F I N V I B S I Q U F A D K W H L R & U K D D Q M X P
S R V W S R Q H G L Q G H I L Q L W H O \ V E M P R D I X Q H L X R P R / U K H I S J M H D W M K Q R X L O N G R Z W H K R Q R
L Q L W L D O H Q U L F K P H Q W S U R R H V / Z B Q Q G X U D Q L X P Q H D Q X B L Q Q W L P A K L P H H / Q R V I 3 H
X U D Q L X P D Q G D E R X W W K H V 8 D P R X D O P G R X Q Q W R D D D Q H D L Q K H U Y R H S R V P W L R Q F
W K D Q W K H R U L J L Q D O '8

Nuclear Reactor Fuel

:KLOH '8 FDQQRW EH XVHG GLUHFWO\ LQ QXFQH DU UHDFWRU IXH
UHDFWRU WR SURGXFKI SOKWRSQQLXXW RQLXP RQFH H[WUDFWHG FD
PDNH PL[HG RILGH 02: UHDFWRU IXHO W\SLFDOO\ 3X DQG

Down-blending Highly Enriched Uranium

'8 FRXOG EH EOHQGHG ZLW K FZKHDS RQWQD Q U XDRP HP Q NJHK D R PHQHULF L D O
IXHO TAKLRQ RLSV PHWKRG WRWLRLQ XFW HDW KSD T XD R QI KDH UQHGFOXHDLUR Q L C
ZHDSRQV VWRFNSLOH

Munitions

'8 P H W D O K D V E H H Q X V P H G L V X S G V R Q D P V R / Q W R V Q V R D Q D G V Q Q Q N D U R P R U D Q G D
S L H U F L H Q F J W S L Q R H W & R Q Y H Q J W I B R Z Q H D H O X Z V H D G S R Q W V X V H L Q D Q G * X O
1 \$ 7 2 R S H U D W L R Q Q Q G Q % P R V Q R L Y D R

Shielding

7KH KLJK DWRPLF QXPEHU = DQGDKHJ\G \BQHQH\FWDOHQW \RWH
IRU VKLHOGLQJ SHQW RQRPRU UHD\WL \BQG JDPPD UD\V

Counterweights

7KH KLJK GHQVLW\ WKDW LQ SDUW PDNHV XUDQLXP VXFK DQ DV D VPDOO EXW KHDFUFIRIXQW VQ GZRHW KHW VQ PDLODU DSSOLFDWLRC

, W V K R H Q Q R D M M G L W K H W F D U A F D S W L R Q 0, / 8 V W L S X O D W H V W K D W ' 8
' H S D U W P H Q W R I ' H I H Q V H 8 ' I R R Q F M Q W W U K D W H R D Q R I O H V V W K D Q E T
D 8 F R Q F H Q W U D W L R Q R I D S S U R [L P D W R C \ W R D E Q Q Z H B J R W \ , Q D G C
F R Q W D L Q W U D B H D R I R I X Q H W H R E M Q L G R C F D R W H V W K D W S D U W R I W K H G H S
I U R P U H S U R F H V V H G X U D Q L X P

7R GDWH WKH DERYH XVHV R1P1BOKO YSHR UFVR LQRQX PRH GWK QO& DQ VWR
RWKHU XVHV IRU '8 KDYH REIHZKOPESJUKRAS RI WY & OSWRLPQ QWIR H DF RQJ/QIPILF
DPRXQW RI WKH VWRUHG '8 \$GGLWLRLDQJ SURSRVHG XVHV LQFC

High-Density PU Shielding

'8 PHQW D KV DV EHHQ XWKLGI QSGV QRD PWSL RQKVH KLJK FR V W VR R FPRHQWYDHOU W ID Q
SUHYHQWHG PRUH ZLGHVSUHDG XVH 2QH SURSRVDO EHLQJ FR
DSSOLF DWLRQV LQ VHOI VKLHOGHG VWRUDJH ER[H V IRU UDGLRD
BQVLWH VWRUDJH RI FLYLOLDQ UHDFWRU IXHO

Cask Fill Material, Repository Inert Material, or Back Fill Material

'HSOHWHKG & EHHQ SURSRVHG I RQ XSH QDW IX HLOOQ XFIQDM BULDDW WH
FRQFH SW LV LQWHQGHG WR SURYLG KIRRG GR WIEB QWD OF D QLMQ GD RJL C
UHGXFH WKH ORQJ WHUP UHOHDVH RI UDGORQ XFIQHLQ HSURSRSR VHGLP
UHSRVI WRUJ LQHUW RU FEDENILQO PRWHULDQ

Counterweights for Forklift Trucks

8VH RI '8 PHWDO FODG LQ SIUQ WSHUFWLVY B W FWRXHOWHULZHQ KQJ V ZR
GHVLJQ RI IRUQG LO WIW VKHDWLFRUX QVKDHGWDFZH LVOLPH UHGXFH WKH W
IRUNOLIWRXOGLDOORZ ZARKUHQDQNZHUV WRVOHV LQFUHDVLQJ WKH
VSDFH

'HSOHWHG 8UDQLXP DQG LWV &KHPLFDO)RUPV
'8FDQH [LVWKIHOP LDFQ\O IRUP LQ ZKLFK XUDQLXP RFFXUV 6LQFH D
WKH VUDHPDFWLRQHQV DLOQG QKDDW\K DOPPLRFVDM\ LFQKHQW\WE\WHDQ\LSKWL FV QDWXU
GHSOHWHG XUDQLXP DUH HVVHQWLDOO\ FKHPLFDOO\ LGHQWLFD
WKH HQYLURQPHQ\WR FDQHQGP \WFKDQ\ VDQPGH ELROBQLER\OG\HI\\$HQFWGLRQUMHQ
H\LVW EHFDXVH RI VPDOO PDVV GLIIHUHQFH V EHWZHHQ YDULRXV

& K H P L F D O O \ '8 L V L G H Q W D Q D Q P W R B U N Q R H U R B D Y Q L D H W X N U B I Q L W H Q J H Q W
F D Q U H D F W Z L W K P R V W H O H W K Q W D L U H [E H M S W R U P W H R [J D G V H H V V X , F Q K D V
D Q G W U L X U D Q L X P R \$ W D U R R B @ H W I P S H U D W X U H K X P L G L W \ F D Q S U R
: K H Q X U D Q L X P L V F I K U L D S J P H Q R M Z G G H U Q D Q G W X U Q L Q J V W K H P H W D O E
V S R Q W D Q H R X V O \ L J Q L W H V L Q D D Q M P E S W D Q L X R H I P V L F S D U R G R K U F P I G L L Q Q F
R [L G H V X Q D Q Q L X R P U K G H X U D Q L X P W H W U D I @ X R W R Q B H D H Q S O X D L L Q Q H L G X I
E H O R Z L Q J U H B I W S K U V G I F T D O L S O U P R I S R I U W W M V P F R S R M R W D Q W X U D Q L X P F R
J L Y H Q L Q 7 D E O H

Uranium Oxides

8UDQLXP R[LGHV BQ FDOQGG HK LBD QLXP W UPB R2V BG 832UH VROLGV WKD
UHODWLYHO\ VWDEOH RYHU B RZQ GLHW U B QVH ZRUWHQ B LQIRZ P RQ XELOO
IRUPV WKH '8 LV FKHPF DQWD P QH HI RVWD RQH W Q O PLVWRKUD JPHR RW
VWDEOH IRUP RI XUDQLXP DQG LV WKH IRUP PRVW FRPDRQO\ IRX
LV ^\HOORZ FDNH ' D VROLG BUQG KQH CR SGXWDLQ U RPQLQ LDQG QG P HG
\HOORZ FRQRUD V8R2OLG FHUDPLF RID XWHDQ DXOP B Q G WV KIRPIRRQO\ XV
UHDFWRU IXHO \$W DPEJLUHQGAK DVOHOP S P2RQO YHKUMHW W8R2 8

Uranium Hexafluoride

8UDQLXP KH[DIHOKRHIPGA DLOV MRK P RI XUDQLXP XABQ B IX UDL QJR OIQU L
OLTXLG RU JDV ZLWKLQ SDHUB DVKRQHVE DQGIUS DQHMDRZKWLWPH 6 B QI QG H
FU\WWD0OLQH B DQJHURB Q VUDQHVE IQLQWU BHDQF WQ ZWWR JRHQ F DUE R
GLR[LGH RU GU\ DLU LW G B HYD SJRHUD FAWR Z RWR Z B WUHRV R VHZ B WGHUR
XUDQ\O IOXRUL CHH FDXWHD FWV ZLW KQJD KXHPU VGLKOFOLKOG LW LV DOZ
KDQGOHG LQ OHDN WLJKW FRQWDLQHUV RU SURFHV VLLQJ QRQW VV
IDYRUHG DV D FKHPFLDO IRUPGILRUS RVRQQ FHHFDPX VM RRU DJWV UHODW
, Q XUDQLXP FRQYHUVLRQ DQMI RIQ UKDQ BQH QM VD DSQGRQH QD HRO XRDUDPQH
8) ZKLFK LV FKH PLFDOO\ WR[LF 8UDQLXPW KLQ RALKHWXH UMLWWF DVM
KLJKO\ WR[LF K\GURIOXRULF DFLG

Uranium Tetrafluoride

8UDQWHPWUDIOXRWR BHWBP HV FDOQH B UHPWQH B DQWDEQURUD HL V D
VROLG FRPSRVHG RI DJJOR PWMD B DQJPSRD LEVD NLVQ QWQ G TS B DDWMDQH
QRQK\GURVFRSLFR QEGDMO BOK WOKH Q H[S R WHOR ZOR ZG QVHRJO VHZ V D G
XQGHUJR HV K\GURO\VLV IRUPLQJ VHYHUDO SRVVLEOH XWDQLXP
JHQHUDO\ DQ LQWHUPHGL DMRHXIUQ QNLXHP RRUZG RRUZG RRUZG IRX P8)P HWDC

Uranium Metal

8UDQLXP PHWDO LV DPRQJ WKH GHQVHVW P DJWIDP VDSHVUNFOREZQF FZ
J FP 7KH VLOYHU\ ZKLWH P DODW DQEROWH D DQGW G B DW LQH XPHDVQD X P
XQGHUJR VXUIDFH R[LGDWLRQ ,W WDUQLVKHV LQ DLU ZLWK WK
PDWHULDO DW UR RPPWPHPV BQ BSRXQH S/V8 B DQOQ XLJQLWH VSRQWDQH
WHPSHDXUH

ODQXIDFWXULQJ (QULFKPHQW 3URFHVHV
7R SURGXFH XUDQLXP IRU FRP B HDUSFSWDLOR QV D WWRVW UXDHQDQHUE P LQW
PLOOHG HQULFKHG DQG F B QQH XHPWIRG HWRR Q WKDXLDEQH BZHLXW
7KLV RUH LV BLD B FHVW BQJL B PFKFB B VXUHV WR VHSDUDWH WKH X
UHPDLQGHU RI WKH RURG XTRKH ^XHWDQRLXFF B N B QVDSRZGHU FRQWDL

6LQFH LVRWRSHV RI WKH VDPH HOOPHQW KDYH WKH VDPH FKHP
E\ XVLQJ SURFHVHV W KLDW OD QH I EHDXWQHOF RQ EHKW ZSHKQ LVRWRSHV
RI PHWKRGV KDYH EHHQ GHYHORSHG WRVH RQLFIDV B QMPLIX QHF
HOHFWRPDJQHWQ FJ D VHS B XQBLRQH RQOLW KHFGRPA ILUVW FRQYHU
\HOORZ F2DNLHQW R XUDQLXP KHDQ KQXIROLQH RQVHL VDYL VDVO ORKZH G W
WKURXJK D SRURXV EDUUBL B O HZKXQHUVW DKLHH OQKJWQHOU\ PRUH OL
EDUULH B KHDQ B HUR OHFXOHV 8)DQG B X VPHROHFXODU ZHLJKWV DUH

VDPH WKH JDV LV RQO\ V O IDJJKW O\ KHHQ W\ \ F KLH/G SODQ/W\ D\ W\ J\ K\ O\ H\ X\ J\ K\ L\ D\ 8 IUDFWLRQ LQ WLWHL QDFW\ H\ RDX\ V\ H\ G\) W\ R\ H\ Q\ K\ W\ U\ H\ Q\ T\ D\ K\ G\ L\ G\ H\ Q\ U\ H\ R\ Q\ K\ L\ M\ F\ K\ P\ V\ K\ X\ U\ D\ Q\ L\ X\ P\ S\ U\ R\ G\ X\ F\ H\ G\ D\ O\ D\ U\ J\ H\ T\ X\ D\ Q\ V\ S\ L\ W\ V\ R\ D\ O\ V\ R\ F\ J\ R\ Q\ W\ D\ D\ Q\ V\ L\ H\ Q\ G\ J\ D\ D\ V\ E\ R\ 6RPH RI WKLV '8 KDV EHHQ X\\$H\ G\ U\ W\ B\ R\ A\ U\ D\ S\ A\ K\ Q\ D\ R\ U\ M\ D\ X\ Q\ C\ H\ P\ D\ W\ F\ R\ R\ Q\ W\ U\ D\ F\ W\ P\ D\ Q\ X\ I\ D\ F\ W\ X\ U\ H\ S\ H\ Q\ H\ P\ W\ H\ U\ D\ D\ B\ R\ Q\ W\ U\ Z\ D\ F\ R\ M\ R\ U\ F\ R\ Q\ W\ U\ D\ F\ W\ R\ U\ T\ K\ S\ H\ H\ L\ D\ 6\ W\ H\ G\ I\ D\ 1\ X\ F\ O\ H\ D\ X\ U\ O\ D\ W\ R\ P\ J\ R\ L\ V\ V\ I\ & R\ Q\ Q\ G\ 5\ B\ H\ Q\ W\ H\ G\ W\ D\ L\ F\ H\ Q\ N\ F\ H\ R\ Q\ W\ H\ Y\ D\ F\ W\ R\ U\ V\ W\ R\ S\ R\ V\ V\ W\ R\ U\ H\ '8 D\ Q\ G\ W\ R\ P\ D\ Q\ X\ I\ D\ F\ W\ X\ U\ H\ W\ P\ X\ Q\ L\ W\ L\ S\ R\ Q\ F\ D\ F\ R\ O\ P\ L\ F\ R\ I\ Q\ W\ Q\ W\ Z\ R\ X\ L\ O\ R\ G\ P\ W\ R\ U\ H\ F\ H\ L\ Y\ H\ G\ W\ H\ S\ D\ Q\ W\ H\ S\ R\ G\ J\ W\) L\ W\ W\ R\ D\ P\ D\ Q\ X\ I\ D\ F\ W\ Q\ G\ L\ R\ Q\ W\ P\ D\ H\ F\ A\ L\ D\ Q\ W\ Q\ R\ W\ K\ H\ '8 F\ R\ P\ S\ R\ Q\ H\ Q\ W\ V\ W\ R\ D\ V\ Q\ W\ D\ R\ X\ I\ W\ M\ K\ R\ H\ L\ G\ H\ S\ O\ E\ K\ W\ H\ H\ G\ X\ Q\ R\ Q\ L\ X\ W\ R\ K\ U\ H\ H\ G\ I\ C\ L\ Q\ F\ O\ L\ Q\ G\ H\ U\ V\ D\ W\ W\ K\ H\ J\ D\ V\ H\ R\ X\ V\ G\ L\ I\ X\ V\ L\ R\ Q\ S\ O\ D\ Q\ W\ V\ Z\ K\ H\ U\ H\ L\ W\ Z\

86(& ZDV FUHDWHG DV D JRYHNUQRIRQWR IF WUKSIRUHQWLFRKQP MQRWV KIDSDI
FLYLOLDQ XVH ,Q WKH HDUO\ V 86\$RIZD W LFRUQH DMKIBGV DEVH FDD JPRH
ZKHQ LW ZDV SULYDWLJHG LQ 7RGD\ 86(& ,QF LV WKH ZR
IXHO IRU FORQPHFOFLDUHSO\QUDQWDQH H QULFKPHQW SURFHVVHV R
.HQWXFN\ SODQW DQG SHUV RXUQP WHVRQD UREKWD QIG WOKHE BQDWRORXW

'8) FDQ EH VWRUHWG± DQ TVKLG HRJUDIWHIRROXEVG H Q\$WVWDHPXSUHV DQG SUHVV
'8) LV D VROLG WKHUHIRUH LW LV QRW HDVLO\ PULHQIA DZLHWG IW RI
ZDWHU YDSRU LQ WKH DLOLQQE UWKHX USDXQXRII DWQRDXLQGR/QDFQRGP S
VPDOO DPRXQW RI +) JDV LV FUHDW HGH DVLIGWIUQJP VDKELUDHPFKQG

0 RVW RI '2(¶V '8 F R Q W Q W Q \ E H W Z H H L Q K W S V R U F H Q W X U D Q L X P
X U D Q L X I P X R I P D G H R U 8 X U D Q L X P W H W U D H O O X I R H Q B Z O H Y H O V Q H F H V V D
Q X F O H D U F K D L Q U H D F W L R Q \$ O D U D H L V O M R L R Q N S K Q H S D P V H W D H Q F R
F \ O L Q G H U V V W R U H G D W '2(¶V P H Q Q X J F D K F P W A X Q W L Q D F D Q Q G W L H H W W L Q J I D F
6 W D W H V D U H S Q Q M L G H Z G K L Q H \$ S D S L M Q / G D [O L V W L Q J R I V L W H V R Q W K
P D \ K D Y H '8 F R Q W D P L Q D W L R

7DEOH 3K\VLFDO 3URSHUWLHV RI 8UDQLXP &RPSRXQGV
&RPSRXQG 0HOWLQJ\&3RLQW _____ 'HQVLW\ J FP 6ROXEL\O L~~WWWW~~ USPELHQW
7HPS~~WWWW~~
&U\vwDO %XON
3DMEOH

8 U D Q L X P + H [D I O X R U L G H
8) ' H F R P S R V H) / W R 8 2

8UDQLXP 7HWUDIOX RULGH
8) " "

'HFRPSRVHV WR 82

8UDQLXP 7HWUDIOXRULGH
8) " "

9HII\ 6OIJKWO\ 6BOXEON

8 U D Q \ O) O X R U L' G H T R B S R V I Z V D W R 8

6 ROXEOH

a

7 U L X U D Q L X P 2 F W F D R R Q S Q M H V D W R 8 2
82

6SDULQJO\ 6ROXEOH

8UDQLXP 'LR[LGH 82
“

6SDULQJO\ 6ROXEOH

8UDQLXP 0HWDO 8

6 S D U L Q X E O K R O

6 RXUFH KWWS ZHE HDG D QROP S R X QGQ ISQIRXSPH U XWLGHW XX PW DEOHSK \ VSURS FIP

\$\$\$\$SHQGLQHDXUHPHQW 7RRQV DQG ORQLWRULQJ 7HFRQ

0RQLWRULQJ XUDQLXP LQ WKHLUHQFLPUHDQPHUQHMP HLOQWV\ XDGHQ/ DEQDWKIV
VDPSOHV LQ WKH ODERUDWRU\ 6LQFIDWLRXQHMLQDDEQWQWKRBLQHOUDEOHW
FRQFHQWUDWLRLQ RI QDWXUD\W\XUIBQLXIDYQD\PHD/OJLQHDWD\QDRQNDQ
SUHVHQW DQG VR LVRWRSLF DLQD\W\VDHO/VIBULHP\\$IRQMWUDQDOWW LQHFAHG HD
GLIIHUHQFH EHWZHHQU\QHXKD\W\KQD\W\IDQ\QRPQ\BWW\KHUH FRXOG EH V
ZKHQ D VLWH FRXOG EH UHVI\\$RJQW KHOQD\W\U\W\IOHX'\\$DCEIX\Q R\W\ KDT
WKH WRWDO XUDQLXP SUHVHQW FRXOG KDYH EHHQ HLWKHU EDFI

7KH IROORZLQJ VHFWL RQV \$ Q RRYULPGDHTWLRQDQRLQOPWHQLRQAG XFRVRDQ\ D Q G P
WHFKQLTXHV XV HNGKIRRXLO & UDOQ\ \PEH Q RWHG WKDW (3\\$\\ KDI V UHFHQ
UDGLRORJLFDO IRU WKRQHODWLRQH B DZGLWPRDFWHLQHHDQVH IURIQQ\\$\\ DJH
DQG WKH LQWHUHVW H W HNGKIRRXLO DZGLWPRDFWHLQHHDQVH IURIQQ\\$\\ DJH

) L H O G O H D V X U H P H Q W V
) L H O H V P X H Q P V D U H W I \$ H G F D Q D K U S I D Q D G R E X T W H U V F D S D E O H R I G H W H F
 S D U W L F O H V P I Z Q Q D V B J G D M Q F S U V L U E N H L F D V H V L Q V S W L B D P D Q V S V R M V C R H D Q H V V
 W K H V X U I D L Q H D W R Q Q D G P X H L W W V R L D Q Q O U D G S R Q Q X E F B O K L G H V L S Q U A V L V C Q D W W L R Q
 G H W H F W R H M Q R B Q V H G L Q W Q B I U S J D V D W U H E D X W D V L R Q B D S B R R Q R V U H U V K D
 E H H Q I W R Q E G H P R U H V X L W D E O W V R Z U K H U H P H O G R I P T H M V B D W H H I E W I R Q U Q I G >

7 K H 0 H D V X U H P H Q W V \$ S S O L F D W L R Q V D Q G ' H Y H O R S P 2 H Q I W * U R X S D
F R S D U H I G S W I K D R Q H R I V B D K B I Q G K W M D V G R E P H R Q F R V H G W R 8 I G Q H W R I E Q V >
' H W H F I W H R Y U L V H Z H G L Q F O X G H Q Q V D I R U H ' Q Q V H Q E W M B Q P R I / R Z (Q H U J \ 5 D G L
' I ' V R G L X P L R G L G H H Q , D Q Q H W Q I R W S R Q Z D Q G R E Z S S H G H W H F W
R S H Q Z L Q G R Z S D Q F D N H G H W H F W R U V K R Z H Q H K W I D H G H W W W F G H R W H F W L
S U R Y L G H G P R U H F R Q V L V W H Q W U H V X Q W V

) L H O G P P H D Q W X U H V L Q J H W X H W W M D U P H G E Q M R L U \ L C J H V X U U Q D M F R R Q W D R H
G H W H F W L R Q R I '8 E H Q Q R I Z D V Q K G H X R I X Q S P R Q X O H D J W L R Q Q F L K D P E H U V D Q C
F R X Q W H U V L V K L H Q R E B R W S W L E R E M R V I D D S D S U K W L D F Q Q G I V L Q W K H V R L O + D
V S H F W U R P H W H U V F D Q G H W H F W '8 E H O R Z W K H V X U I D F H E X W W K H
H P L V V L R Q V E L J Q L I L F D Q W O \ U H H G X F R I V W K K L H V H W H F F K V Q I L Y T H Q I R U I L H O G
V X U Y H \ > @

/DERUDWRU\ \$QDO\VLV RI (QYLURQPHQWDO 6DPSOHV
\$ QPEHU VR\ FDDQD \H WKRGV K\ YHR E\ X\ Q\ H\ M\ R\ Q\ M\ Q\ D\ U\ B\ Q\ B
(QYLURQPHQWDO \K D\ W\ B\ Q\ H\ L\ Q\ H\ D\ Q\ H\ L\ O\ W\ H\ R\ W\ D\ V\ Z\ D\ Q\ G\ U\ V\ R\ L\ O\ >
\$ QDO\WLFD\ O\ B\ H\ E\ V\ K\ A\ K\ G\ F\ K\ P\ H\ A\ K\ O\ R\ D\ W\ X\ G\ H\ X\ Q\ H\ O\ L\ O\ R\ K\ H\ O\ W\ R\ W\ D\ O\ R\ I\ T\ X\ D\ Q\ W\ L\ W\ X\ U\ D\ Q\ L\ X\ P\ D\ Q\ G\ U\ D\ G\ L\ R\ O\ R\ J\ L\ F\ Q\ Q\ I\ V\ P\ K\ M\ K\ R\ X\ G\ L\ Q\ Q\ V\ A\ L\ K\ V\ D\ L\ B\ K\ E\ D\ Q\ V\ G\ R\ H\ S\ N\ Q\ H\ L\ X\ P\ L\ & K\ H\ P\ L\ F\ D\ O\ F\ H\ O\ W\ K\ G\ R\ H\ G\ N\ L\ Q\ Q\ I\ W\ L\ F\ S\ K\ R\ V\ S\ K\ R\ U\ H\ V\ H\ F\ W\ Q\ F\ H\ D\ Q\ Q\ D\ P\ D\ W\ W\ W\ V\ S\ H\ F\ D\ W\ \$P\ R\ Q\ J\ W\ K\ H\ P\ R\ V\ W\ F\ R\ P\ P\ R\ Q\ U\ D\ G\ L\ R\ O\ R\ J\ L\ F\ D\ O\ P\ H\ W\ K\ R\ G\ V\ D\ U\ H\ D\ O\ S\ K\ D\ Q\ H\ X\ W\ U\ R\ Q\ F\ R\ X\ Q\ W\ K\ Q\ H\ Q\ D\ Q\ Q\ G\ L\ Q\ H\ X\ W\ U\ R\ Q\ D\ I\ F\ M\ A\ L\ Y\ D\ P\ W\ M\ R\ K\ Q\ G\ Q\ D\ Q\ H\ E\ U\ L\ H\ F\ H\ O\ R\ Z

Kinetic Phosphorescence Analysis (KPA)

.3\$ LV D PHWKRG WRK D~~W~~ W H V~~X~~ Q D~~Q~~ E~~R~~ X~~P~~ V W R O X W L R Q D Q G W K H Q P H P I V V I R Q Q X P I Q H V E H Q F H I Q W M H Q R I W W R V Y C H P M F H P I H V S A K R H S R Q W H R Q

TX D Q W L W \ RI X U D O Q H L X P T K I Q W S H U F R K Y Q D G P H S V Q R L Q I R U P D W L R Q D E R X W D E X Q G D Q F H V R I X U D Q L X P W Q Q J X L K K U B I R U R P Q D Q Q R W O G X V D Q L X P

X-Ray Fluorometry (XRF)

;5) LV V L P L O D U W R . 3 \$ V R E X I W F I X W H; W U H D I D O D O R G / D H Q F H D Q I W Q W H V U D I P S O 7 K H V H F R Q G D U \ ; U D \ V F K D V D F Z D N Y B I O V M Q L F V R V W K H H O H P V I O D W H V K D W V H S D U D W H G E \ Z D Y H Q U H D G F J V A L R U M D Q U D L J W K G W I K H D S S U R S U L D W H O D W P H D V X U H P H Q W R I W K H U D Q W K H H Q F J V A L R U M D Q U D L J W K G W I K H D S S U R S U L D W H O D W L Q I R U P D W L R Q D H E Q R V W L V Q U W K M H A U L F D S O H L Q F D O X G L Q J Q X R U M Q S I L X R P Y L G S H G L Q I R U P D W L R Q D E R X W W K H L V R W R S L F F R P S R V L W L R Q R I W K H X U D

Mass Spectrometry (MS)

0 6 L V D W H F K Q D T D H V M A N Q D D V Q I C V D V R I C V R U E D W W K R P B D W W R K P D K U H J H 8 Q O L N H P R V W F K H P H L W B D Q G R H W W R K G V S U R Y W G L H V H T L Q D I Q W P D W L R D D T E B D Q W L E V R W K W X U D Q L Q P W K O H H V D Q G W K H S I R W R W R S Z I K R F V A M Z F P P P R Q 0 6 W H F K Q L T X H V T X D Q W L I L F D W L R Q R I X U D Q L V X D U I Q D M Q R Y Q U R D Q M P I H R Q Q W B D V X D D P S D D Q H V U R P L Q G X F W L Y H O \ F R X S O H G S O D V P D B D Q V W L Q S H H F W H L Q R A P O H V S W I B G H & K B D G I C E H P H W K R G I R U W K H G H W H U P L Q D W Q R H Q Q R L U R I Q R I H Q P W D Q R W D R P S S L O F H V D E W H V H Q V L W L Y L W \ D F F X U D F \ D Q G S R U Z Q E L W B R S Q U L R E Y D M B & B L Q U S D K F D V D Q I C H C S U H F L V L R Q Z L W K K K U I R J X K J H K S X V D P D S C O G H H D V H R I X V H > @

Alpha Spectrometry

\$ O S K D V S H F W U R P H W U \ L V B D Q P M I M K R B I V D K J D W Y H U Q H O D O S K D W P K I H W T W L Q J Q X P E H U R I D O S K D S D U L Q M F I H F O B I G L Q R I Q W F I O W Q H G E V H H V L D W W D R Q S H K B U S D P I R U H H Q H U J L H V L W L V S R V N D E S H H D H N R L Q S H W D D W S H H W W I X D P U W I R R V K H T X D Q W W K H V D P S O H \$ O S K D S D U W L F O M W H F I R Q M F L V Q X R Q W K I H Q O D R U K H H V M B I B U N D P I D Q G Z L Q O O R Q O D D H V K R U W G L O R W B I Q F G I O E W I K R H U J W H I Q H H U J \) R U W K L V N H S W W K L Q D Q G S O D F H G Q H D U W K H G H W H F W R U

Gamma Spectrometry

* D P P D V S H F W U R P H W U \ L Q Y R O Y H H H P L K W H W C H E C Q / E H R Q W X L F R Q D Q L R I Q R P O L I G D W \ S L F H D B Q \ D P P V D D W D R Q R U I R U G H V H F Q U H W U L K H V D B H S D H D N V I P Q D W Q H J D V S H P V F D Q E H U W G T B K W Q Q / L W R R S U W Q M H D S J D U G L R Q X F O L G H 6 L Q F H G X U D Q L X P H P L W R J D G P L P I D H U B I Q W H Q S I H B W H U R P J H D V P D F D Q E H X V H G W R D E X Q G D Q B I Q R U X P L V R W R Q S M V W D D Q K D C B N X W D Q L X P K D 8 S Q D O L W H F D G S J D P D U D \ V F D Q S H Q H W U D W H V R L O D Q I G V Z M D V Q H F B I I D Q B F D K Q I E H R X G H F W

Instrumental Neutron Activation Analysis (INAA)

, 1 \$ \$ L Q Y R O Y H V W K H I S U O U H D B I L V I Q Q R M Q R V R S I D R G D P H D Q D F W L Y D W L R Q S

\$ Q D O \ W L F D O \ O H W K R G V I R U \$ L U 6 D P S O H V
\$ L U V D P S O H V D U H W \ S I H F D \ O S H I R R \ O O I H F I W \ O \ W H R U Q D \ O R Q P I \ W I K W \ Q R D G Q / D O \]
G H V F U L E H G L S Q U F O X L G R D Q / J O D \ & \$ K D V S I R F W , U B \$ H W U \

, Q B H W K R G X \ V 3 H S Q V E 1 D W L R Q D \ D V \$ R Q \ D Q \ B L Q S / B R D \ D \ O W D R E \ S 5 / W K H D L U
I L O W H H W H D G U V R L Q M F D Q W L V W K R Q Q D R W H Q L I J H G R D \ L G H X U D Q L X P L V H [W U
W U L L V R Q H F W S \ D P L L H G D E Q J D H Q E R Q B H D \ S M A G F R S U H F L S L W D W H G Z L W K
I O X R U L G H 7 K I K H X Q U D R Q Q \ & F L V H V G E \ I L O W U D R V I L R Q 8 D Q Q Q C D U H H G 7 K I
P H D V X U H G E \ D O S K D L W S P H H F A W K U R R G P H W \ V H \ K W R Q D P L H D D X U S H D X W D R Q I L X V K H
(Q Y L U R Q P H Q W D O 5 D G L D W L R Q \$ P E L H Q W O R Q L W R U L Q J 6 \ V W H P > @

, Q D Q R W K H U P H W K R G G H V F U L E I H Q G W E H U V L Q W K H D D Q / K H I G H Q Q Q I G D L V V R O \
Z L W K L U R Q K \ G U R R \ L Q D H D \ D Q Q B F D \ D Q H L X U P D Q L X P L V I \ & B W K R Q \ D Q Q G L I L H C
H O H F W U R G H S R V L W L R Q G S S B H / W I R B E I A Q R / Q R O O X W H R D Q R I D V U H S R U W H G X
V S H F W U R P H W U \ > @

\$ Q D O \ W L F D O \ U H W D K A R H G W \ B P S O H V
(3 \$ ¶ V (Q R Y Q P H Q W K B \ S R D U Q N G \ & S E X R E U Q D W R K H G V W D Q G D U G L] H G S U R F H G X U I
P H D V X U H P H Q W R I U D G L R D F V L I Q Y F L O X K G H Q G Q W D Q Q N L I X Q P J D Z Q D D M H V L W K E D W E R
I O X R U R P H H W W K U R G V > @ D Q G P R U H U H F H Q W O \ G H Y H O R S H G D Q , & 3

, Q W K H U D G L R F K H P L F D O P H V S K R V G W M I G H Z X W D Q I L H X P U L \ K R G S U R H I F G H
H [F K D Q J H F K U R P D W R J U D S K \ D Q G F R Q Y H U W H G W R D Q L \ V U D W H V
S O D Q F K H W G U L H \ J D R Q V I O D S K H D V X F U H G H X V W L K Q H / U P D J D V I O R Z S U R S
F R X Q W H U R U D V F L Q W L O O D W L R Q G H W H F W L R Q V \ V W H P I R O O R Z L Q

) R U W K H I O R R I W R K R H G W X I U F D Q L X P L F V R S E R I Q I E S I L Q M D V D I O R K O S K E R W \ S K D D O V X P L
G L V V R O Y H G L Q G L O X W H G Q L W Q I L V F U D D F V L \ B R Q D W \ D Q W Q L Q J P D D J Q H Q V W L X P
X U D Q H X D F U W H G L Q Q D \ R H M M D K M H D X Q Q G Q G L U X L A S V G R O Y K H \ L Q Q L W Q U X L F U D G I H G
I O X [L V D G G H S O H D Q G X W H K G R \ D R U \ Q K H D W V R X U F H

7 K H , & 3 P H W K R G Z D V G W Y P H H D R V S H U G Q J R W R W D Q Q G X Z L D D Q W L H P Q L R Q K D W D H P L S D
S U H S D U D W L R Q L V P L Q V R D Y Q G X P L Q D M Q D D M B E R I G S E R U J H G M W L R Q I R U W R W
X U D Q L X P 5 H F R Y H U \ L V T X D Q W H V D W T X H R Q V P D D Q G U V R H D R L Q Q G Y D W I W
O L P L W V D : Q H / O R I D T X H R X V V D P B S N Q H M R D Q / R Q O L Q G V D P S O H V >

\$ Q D O \ W L F D O \ O H W K R G V I R U 6 R L O 6 D P S O H V
(3 \$ ¶ V 2 I I L F H R I 5 D G L D S W U R K Q D \ D Q Q H Y Q Q R R S H G W H Z R U D I G W K R I G H / P I L F D O D
X U D Q L X P L Q Y D U L R X V H Q Y L U R Q P H Q W D O P H G L D L Q F O X @ L Q Q V R L O
W K H I X V L R Q P H S O W K R G D W K H G / D W K H V L O L F D Y R O D W L A D J X H R G U L G K H V
D Q G S \ U R V X \ S M K D D W T H U D D G G H G H [D V Q G D Z W W H H G W W D Q V R R F W \ O D P L Q H S
D Q L R Q H [F K D Q F J R I S F R I D F X L P S Q L W D W H G Z L W K O D Q W K D Q X P I L O W H U H G
V S H F W U R P H W U \ L V X V H G W D R Q T X P W Q R V S H I V W B \ Q G L W G H Y V D X S O O H X B R Q F H
F D O F X O D W H \ W K H

, Q W K H Q R Q I X V L R Q P H W K H R G G W K K H V L D D P L S F O M H Y B R D H D W L D Q G G H G G D Q G W
H [W U D F W H G Z L W K W U L L V R R F D V F L Q D P F L R Q S U V A L L S I S A D H G H Z G L W K W Q L W D Q R
W R D S O D Q F K H W) X U W K H P H V D Q V D D W V W K H E V D P I S K D V W S K H D W U R U W K H

7DEOH 6HOHFWHG \$QDO\WLFDO 0HWKRGV IRU 'HWHUPLQLQJ 8UDQLXP LQ (QYL
VHH 7DEOH RI WKH 7R\ULBRUORQJLXFDQ @URRIUODHGIRLWLRQDO PHWKRGV DQG

6DPSOH 0DWUL[6DPSOH 3UHSUDWLRQ \$QDO\WLFDO 0HWKSOH \$FFXUDF\
'HWHFWLRQ /LPLW

:DWHU 6DPSOH IXVLRQ ZLWK VRGIOXFR WQXRWLRQ / 1D) DW
DQG OLWKLXP IOXRULGH MWRWDO XUDQLXP PJ /

:DWHU 3UH FRQFHQWUDWLRQ E\ LRQWHLRQD QHG DWDI R GDWD
FKURPDWRJUDSK\ SXULIL\$FDWLWLRQWE RQRQ
H[FKJHQDQG VROYHQW H[W\$QDFOMVRLQ 1\$\$
8 DQ8

:DWHU ([WUDFWLRQ E\ LRQ H[FKDQOB\ HGLVQHXLWLRQ LQD WD
ORZ R[JHQ VROYHQW LUDQGIODWLRQ WWRQ RWDO
XUDQLXP

:DWHU :HW DVKHG UHDPSOH\ WLRQDQ WL3XIOVHFG ODVHLSSE
SKRVSKRULPHWU\ DYHUDJH

*URQWHLU 6HSDUDWLRQRRQWUHQVLQ DQG QMHFWIPRQ ±" QJ /
, QGXFWLYHQU8
&RXSOHG 3ODVPD
± 0DVV
6SHFWURPHWU\
, , & 06
LVRWRSH
TXDQWLILFDWLRQ

*URXQGZDWHU 6HSDUDWLRQ DQG FRQFHQWUDWLRQKROBZ R1RLGDWD
3HUIRUPDQFH /LTXLG &KURHPWWRJWBDWDO
+3/& OPRQV FRPSOH[DWL RXQJ DQWXP
\$UVHQD]R ,,,

6RLO 'LVVROXWLRQ 1E2) SXULIL\$QDSKLRQ
E\ FR SUHFLSLWDWLRQ VRSYHFMQWR PIRWWUDFPVSLORHQ DQG
HOHFWURGHSRVLWLRQ LVRWRSH
TXDQWLILFDWLRQ

6RLO 6RLO OEDWIKHG&QF+)FO2 \$OSKD 1R GDWDI R GDWD
SXULILFDWLRQ E\ LRQ H[FKSDQJHU RDQHQWVROYHQW
H[WUDFWLRQ DQG HOHFWULRQHWSRSVHLWLRQ
TXDQWLILFDWLRQ

6RLO \$VKLQJ RMLWVLSXP IOX\$OSGD .) 1R GDWDI R GDWD
VHGLPHQWQG SRWDVVLXP6S\URVXO6DWFHWURPHWU\
DQG ELR\$QDULILFDWLRQ E\ H[WUDFWLRQ ZLWK
WULLVRRFW\ODPLQH DQLRQ H[FKDQJH
FKURPDWRJUDSK\ DQG FR SUHFLSLWDWLRQ

6RLO \$VKLQJ HQMQLWBR FW\ODPBRQH \$OSKD 1R GDWDI R GDWD
VHGLPHQWQWULSIURPWULLVRRFW\6DREWURMMKUQLRWULF DFLG
DQG ELRWD2 DQG FR SUHFLSLWDW\$ORSQDZLWK
ODQWKDQXP 6SHFWURPHWU\

6DPSOH 0DWUL[6DPSOH 3UHSDUDWLRQ \$QDO\WLFDO 0BWK\$OCH \$FFXUDF\
'HWHFWLRQ
/LPLW

)LHOG 6X1URYQH

6FLQWLOODWLRQ 1R GDWD
'HWHFWRU DQG
&RXQW 5DWH
0HWHU

\$LU \$LU SDUWLFXODWH FROOHQWXRQLRQ QOPDJVNLIREBDWD
ILOWHU GLJHVWLRQ LQ Q&RIVUSLDFHDFBQQBPD
± 0DVV VRWQKRQ
6SHFWURPHWU\
, & 3 06 WRWDO
XUDQLXP

\$LU 6SLNHG DLU SDUWLFWKHDGW\$ID SKUD DQG ZHOSP 1R GDWD
GLVVRVQRF RJSISLW QZVLLWRKURQ 6SHFWURPHRU\$ LQ
KGRLGH DQG &DR[DODWH SXULILFDWLQRQWELRQ
VROYHQW H[WUDFWLRQ DQG HOHFWURGHSRVLWLRQ RQWR
SODWLQXP

\$LU 6DPSOH FROOHFWLRQ RQ \$FOHSOKDXORVH ILQWH1URV GDWD
DVKLQJ H[WUDFWLRQ ZLW6SHAFWULRQIRWWVODPLQH
SXULILFDWLRFQDEQJBLQLRQ H[
FKURPDWRJUDSK\ DQG FR SUHFLSLWDWLRQ

\$LU &ROOHFWRQ RQ FHOOXORQVHWUV PJ SHB GDWD
1HXWURQ ILOWHU
\$FWLYDWLRQ
\$QDO\VLV
, 1\$\$

6RXUFH 7R[LFRORJLFDO 5HSRUW IRU 8UDQLXP > @ 7DEOH

\$SSHQGL[1DWLWRQHDO/BVWRUJ3D W6KWHW RWUKPD\ KDYH '8
&RQWDPLQDWLRQ

13/ 6LWH

(3\$
5HJLRQ

'HVFULSWLRQ

0D[H\)ODWV 1X5HJLRQKH 0D[H\)ODWV 1XF0\ DOUR FLDWSIRG\ DQG HLDWHWHUQ .H
'LVSRVDO +LOOVERURLOOVERUR LQ)OHPLQJ & RXQW\ DQG HZB\ D GLVSR
.HQWXFN\ 13/ UDGLRDFWLHY ZDVWH \$\$\$PSXUQRGLP\ DMW\ ROXUFH PDWH
FRQVLVWLQJ RI XUDQLXP DQG WKRULXP RU RUHV
0&L RI E\SURGXFW PDWHULD OV DQG SRXQGV
LH SOXWRQLXP DQG HZB\ UELXFKLHHG XQDQD QDPUHD NQ
5HVVWULFWHG \$UHD Z5DDVG GR\ D F RYLMH HOGH WRKDM\ H D
WKLV DUHD DQG LQWR VXUURXQGLQJ IUDFWXUHG
JURXQGZDWHU 7KHD E\K\ PZHD\ L\W\ LFRDQS W\ S\ H RDQG HY
OHDFKDWH SURGXFLWQ\ DWR\ HGI HF RWQFHQQ\ W\ XUDLW\ HGV LQ
GLVSRVDO WUHQFKHV ZKLFK ZHUH XOWLPDWHO\ P
VROLGLILHG DQG EXULHG LQ DQRWKHU RQVLWH G
FDSSHG

0DOWD 5RFNHW5 HJH\ Q\ SKUL\ DV LWH LV ORFDWHG LQ WKH WRZQV RI 0DOWD
0DOWD 1HZ <RUN 13DSSUR[LPDWHO\ PLOH V\XW\KL\ H\ DQDUW\RKJ\ H\ D\ DM\ H
5RXQG /DNH \$OO RU SDUW RI WKH 7HVV 6WDWLR
XVHG IRU D ZLGH UDQJH RI URFNHW DQG ZHDSRQV
DQG RWKHU UHVHDUFK ,Q DSSUR[LPDWHO\ KH[DIOXRULGH JDV ZHUH UHOHDVHG LQ D SRUWLR
EXLOGLQJ 7KH DUH DF\ QW\ P\ H\ D\ Q\ G\ D\ Q\ G\ W\ M\ K\ H\ D\ O\ Z
OLFHQVHG GLVSRVDO IDFLOLWLHV

6DYDQQDK 5LYH\ J\ L\ R\ Q\ D\ K\ 5LYHU KDV \$D\ R\ G\ H\ U\ F\ H\ D\ Q\ V\ X\ F\ O\ H\ Q\ D\ U\ W\ L\ R\ Q\ D\ O\ G
\$INHQ 6RXWK &DUROLQD 7KLV VL\ H\ Q\ D\ Q\ V\ D\ Q\ G\ UDQJHV IURP GU
13/ VZDPSODQG 7KH 'HSDUWPHQW RI (QH\ '2(UHS
RI '8 ZDV UHOHDVHG LQ -DQXDU\ LQWR 8SSHU
HYHQWXDOO\ IORZV LQWR KWHK\ H\ L\ D\ H\ Y\ D\ Q\ Q\ B\ G\ 5K\ D\ M\ LQ
JURXQGZDWHU SXPS DQG WUHDW FDSSLQJ VROLG
EDVLQV DQG VROLG ZDVWH GLVSRVDO VLWHV UHF
RI KD]DUGRXV VXEVDQFH V DQG VKLSSLQJ SURF
3LORW 3URMHFW LQ 1HZ OH[LFR

5RFN\)ODWV 5HJLRQKLV IRUPHU SODQW PDQXIDFWXUHG SOXWRQLXP
(QYLURQPHQWDO DQG VKXW GRZQ R\QH\ W\ S\ R\ Q\ W\ H\ L\ \R\ D\ O\ L\ O\ H\ J\ H\ G\ Y\ L\ R\ C
7HFKQRORJ\ 6LWH *RHQGYH\ Q\ R\ Q\ P\ H\ Q\ W\ D\ O\ V\ W\ D\ W\ X\ W\ H\ V\ ,Q\ W\ K\ H\ 8\ Q\ L\ W\ H\ C
&RORUDGR 13/ SURGXFWLRQ DW WKLV VLWH 'XULQJ WKH VXPPI
GUXPV RI XUDQLXP DQG FRQWDPLQDWHG VRLO IUF
ZDVWH ZDV VKLSSHG WR WKH 1HYDGD 7HVV 6LWH

2DN 5LGJH 5HV\ H\ Y\ D\ R\ Q\ I\ D\ F\ L\ O\ L\ W\ L\ H\ V\ DW W\ K\ L\ D\ Q\ L\ X\ W\ H\ V\ K\ R\ G\ X\ F\ H\ S\ G\ O\ B\ Q\ W\ L\ E
'2(2DN 5LGJH HOHFWURPDJQHWLF S\ L\ Q\ R\ F\ H\ E\ W\ W\ D\ D\ Q\ Q\ X\ W\ K\ G\ L\ I\ X\ V\ S\ Q\ Q\ D
7HQQHVVHH 13/ E\SURGXFW RI ERWK RI WKH VHV SURFHVVHV 7KHU
LQWR WKH VXUURXQGLQJ HQYLURQPHQW \$W WKH
\$FLG 3LSHOLQH ZDV XVHG WR FDUU\ ZDVWH HIIOX

,RZD \$UP\ \$PPX5HJLRQ\ HRZ\ \$UP\ \$PPXQLWLRQ 3ODQW VLWH\ V SULPDU\ D
3O\ W\ Q\ 'HV 0RLQHV DVVHPEOH DQG SDFN D\ B\ B\ X\ Q\ I\ W\ L\ R\ Q\ F\ B\ Q\ G\ H\ Q\ W\ L\ R\ Q\ Q\ & RXQW\ ,RZD 13/ V\ V\ W\ H\ P\ V\ ,Q\ W\ K\ H\ I\ D\ O\ O\ R\ I\ F\ K\ X\ Q\ N\ V\ R\ I\ '8 ZHUH
7KLV KDV SURPSWHG LQFUHDVHG IRFXV RQ WKH V

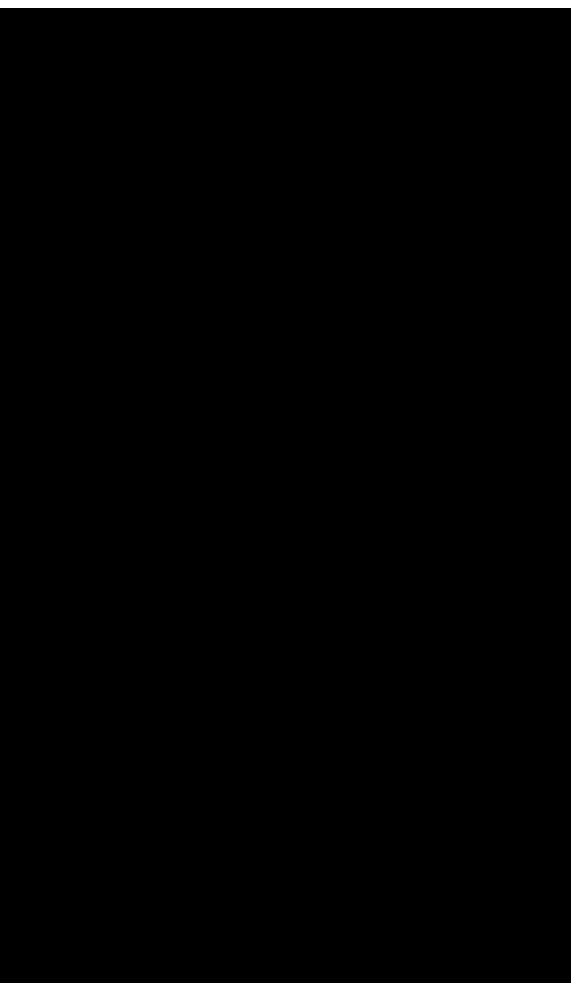
13 / 6LWH

(3\$
5HJLRQ

'HVFULSWLRQ

1DYDO 6XUIDFH5HDJURDQFH& LV DSSUR[LPDWHO\
&HQWHU 'DKOJUHQ
9LUJLQLD 13/

DFUHV DQiÀ ðQà` DWHP



\$SSHQGL[)DFLOLWLHV ,QQYRIOFW&UJLQWKRWKTHVW LQJ RI
 &RQWDLQLQJ '8 DQG RU &RPSRQHQWV RI 3URGXFWV &RQV
)DFLOLW\ 6LWH &RPSDQ\ 1DPH /RFDWLRQ (3\$ 5HJLRQ

6LHUUD \$UP\ :HDSRQV 'HSRW \$HURMHW 2UGLQDQFH &RPSDQ\ 1, , QGXVWULHV +XJKHV +HOLFRSWHU \$UPWHF 'HIHQVH 3URGXFWV &KLQD /DNH 1DYDO :HDSRQV &HQWH&UKLQD /DNH &DO L5HJLRLQD (OJLQ \$LU)RUFH %DVH 0XQLWLRQ 7HD/OMS DDUFLVRLW OR U5B&DL RQ &KDPEHUODLQ 0DVRQ +DQJDU 6SHFLILF 0DQXIDFWXULQJ &DSDELOLQWD K1 P OOV ,GD&KIRJLRLQ 8 6 \$UP\ \$UPDPHQW 0XQLWLRQV &5KHFNL FVOD&QGP S, RDQ&HQRLRQ 2OLQ &RUSRUDWLRQ (DVW \$OWRQ ,OO6&RILRQ -HIIHUVRQ 3URYLQJ *URXQG 8 6 \$UDP\GLVLRQ ,QGLDQ&HJLRLQ 8 6 \$UP\)RUW 5LOH\ .DQV&HJLRLQ 3DGXFDFK *DVHRXV 'LIIXVLRQ 3ODQW&FD2K .HQWX F&HJLRLQ 1XFOHDU 0HWDO ,QF &RQFRUG 0DVVD F&KHKJLHLRQW V 8 6 \$UP\ /DERUDWRU\ &RPPDQG :DWHUWRZQ 0DVV5DHFKLXQHWWV &KDPEHUODLQ 1HZ %HGIRUG 0D&V&D E&VHWWV 8 6 \$UP\ \$EHUGHHQ 3URYLQJ *URXQG %EHUGHHQ 0DU\O&HQGRQ *HQHUDO '\QDPLFV 'HWURLW 0LFKLJ&QJLRLQ 8 6 \$UP\ &DPS *UD\OLQJ *UD\OLQJ 0LFKLJ&QJLRLQ +RQH\ZHOO 0LQQHWRQND 0LQ&H&RQD +RQH\ZHOO &RUSRUDWLRQ +RSNLQV 0LQQHVR&HWD RQ 8 6 \$UP\ 7ZLQ &LWLHV \$OWWQ \$PPXQL1WHIZR&ULJKWRQ 05Q&Q1HR&RQ W D .LVFR 6W /RXLV 0LVVR&HULRQ 5HPLQJWRQ \$UPV &RPSDQ\ /DNH &LWQ \$W&H&Q&R&Q HW D&HQJMR&QW 7DUJHW 5HVHDFK ,QF 'RYHU 1HZ -HUVH5HJLRLQ /RV \$ODPRV 1DWLRQDO /DERUDWRUXRV \$ODPRV 1HZ 6HJLRLQ /RV \$ODPRV 1HZ 0H[LFR \$OEXTXHUTXH 1HZ %H&HJLRLQ .LUNODQG \$LU)RUFH %DVH \$OEXTXHUTXH 1HZ %H&HJLRLQ 7HUPLQDO (IIHFWV 5HVHDFK DQG \$ORF&QWUR 1HZ 0H[LFR \$HURMHW *HQHUDO &RUSRUDWLRQ /RFNZRRG 1HYDG&HJLRLQ 8 6 (FRORJ\ %HDWW\ 1HYDGD 5HJLRLQ 8 6 \$UP\ %DOOLVWLKV 5HVHDFK /D&R&W&R&H&D&H&J&R&QW 6LWH 1HOOLV \$LU)RUFH %DVH /DV 9HJDV 1HYDG&HJLRLQ 1DWLRQDO /HDG ,QGXVWULHV &RORQLH 1HZ <RUN5HJLRLQ :DWHUYOLHW \$UVHQDO \$OEDQ\ 1HZ <RUN5HJLRLQ %XORYD 6\VWHPV 9DOOH\ 6WUHDP 6HJLRLQ /LPD \$UP\ 7DQN 3ODQW *HQHUDO '\QDPLF2KLR 5HJLRLQ)HHG 0DWHULDQW 3ODQW 8 6 ')HUQDOG 2KLR 5HJLRLQ 3RUWVPRXWK 8UDQLXP (QULFKPHQW&R&Q&R X8W&K '2K L5HJLRLQ \$VKWDEXOD ([WUXVLRQ 3ODQW \$VKWDEXOD 2KLR5HJLRLQ 6HTXR\DK)XHO &RUSRUDWLRQ *RUH 2NODKRPD 5HJLRLQ *HQHUDO 'HIHQVH 5HG /LRQ 3HQQV\&HJLRLQ &DUROLQD 0HWDOV %DUQZHOO 6RXW&H&D&R&Q&LQD 6DYDQQDK 5LYHU 6LWH '2(\$LNHQ 6RXWK &D&R&JLRLQ 'HIHQVH &RQVROLGDWLRQ)DFLOLW\ 6QHOOLQJ 6RXW&K5&D&LRLQD \$HURMHW +HDY\ 0HWDOV -RQHVERUR 7HQQ&H&HJLRLQ 0DUWLQ 0DULHWWD (QHUV\ 6\VWHPV2DN 56LQW&H 7HQQ&H&HJLRLQ 'D\ DQG =LPPHUPDQ 7H[DUNDQD 7H[D&V5HJLRLQ 3DQWHI 3ODQW 8 6 '2(\$PDULLOOR 7H[D&V5HJLRLQ *HQHUDO '\QDPLFV)DOOV &KXUFK 9L5HJLRLQ 8 6 1DYDO 6XUIDFH :HDSRQV &HQW&DUKOJUHQ 9LUJLQ&HJLRLQ

)DFLOLW\ 6LWH &RPSDQ\ 1DPH /RFDWLRQ (3\\$ 5HJLRQ
+HUFXOHV 5DGIRUG 9LUJLQL5DHJLRQ
(WKDQ \$OOHQ)LULQJ 5DQJH *HQHUV%OQHGVWURQ 9HUSPIRQRWQ
+DQIRUG 1XFOHDU 5HVHUYDWLRQ 8+DQI2(UG :DVKLQJ5MRSQRQ
8 6 \$UP\ <DNLPD)LULQJ 5DQJH <DNLPD :DVKLQJV5RQLRQ
6WUHVVDX /DEV 6SRRQHU :LVFRQ5HQLRQ

7KH 0DUWLQ 0DULHWWD (QHUIJ\ 6\VWBRVVW.KH KDFLVODZWWQQA VQRLH N7QHFKQ RORJ\ 3DUN LW ZD
DV WKH 2DN 5LGJH *DVHRXV 'LIIXVLRQ 3ODQW

7KLV OLVW LQFOXGHV WKH ORFDWLRQV DQG QDPHV RI IDFLOLWLHV LQYROYHG LQ WKH
LQFRUSRUDWHG LQWR D SURGXFW FRQWDLQLQJ 'HSOHWHG 8UDQLXP '8 ,QFOXVLRQ RQ
WKH IDFLOLW\ EXW RQO\ GHQRWHV WKDW WKH OLVWHG IDFLOLW\ ZDV SDUW RI WKH PDQ
'8 ,Q D IHZ FDVHV WKH FRPSRQHQWV SURGXFHG DW WKH OLVWHG IDFLOLW\ GLG QRW FR

\$\$\$HQGL[& DVH 6WXG\ 1XFOHDU OHWD OV , QF 10, VLW

%DFNJURXQG

7KH 1XFOHDU OHWD OV , QF 160W/DVIPMMW &DROVSRNQFZQODWLWKH LV
SDUFHO ORFDWHG DW OGDLOQH6AMU &IRWQLVQI &RQVFVRDUFK XOLHWVV 7
ILYH LQWHUFRQQHFWHG EXLDGMSQKJDVJ QDQFENRERDQVSHDW NHQJKDWSJHD SR
DKROGLQJ EDVLQ

, Q 10, EHJDQ RSHUDWLQJRDQ PSDUQHXYIDRFXXQGLQDQG F HOFROHD U OH
, QF SXUFHG '8 ISUURGSULPDULO\ DV SHQHVPB\ WIRUVRICR U1DUDROWRSLHU
PDQXIDFRWHD\ GS RZBGIUFD OR WRSIS GRSRISWHLUV DQPHW\\$IOFS DQBXFWV
'LVSRVDO ZDV H[HFXWHG YLDUFDVWWRVWIOH\ B\ VFLVDFUKJHUGJ\ D VWHV
XQOLQHG KRO GIXQJRECO VRLSQHGU\ DQRQFPIGS WRRG YQZOH\ KR D WK
FRSSHU FRDWLQJ WKDW ZDSM EUNHOPIRQH\ SLMQD WQLIRWQUG\ UDLFOLJGZKLFK
FRSSHU DRZGHX\ H\ DQQLWVROYHG LQ WKH QLWULF DFLG 7KH VSHQW
QHXWUDOL]H\ OZKLUK\ DDQLGP\ KHFQQOLQ\ GNRQGEQ\ VRQ\ QDQ\ RQJ ZLWK
ZDVWILWFKDUIJH VQR\ W\ K\ R\ 10, EHJDQ XVLQJ DQ DFLG FO
UHF\FOLQJ SURFHVV

10, ZDVPUHHQ 6WDUPHW &RUS RQDUDWKR\ KLFQFRP SDQ\ V 15 &OLFHQVH
VRXUFH PDWHUQH\ SO\ H\ Q\ I\ X\ P\ X\ G\ W\ Q\ R\ U\ L\ X\ P\ R\ Q\ Q\ H\ W\ K\ B\ V\ WUDQVIHUUHG
0DVVDFKXVHWWV 'HSDUWPHQW RI 3XEOLF +HDOWK 5DGLDWLRQ &
VDSPOHV DQG GHWHFW R\ S\ R\ X\ R\ Q\ D\ W\ B\ D\ M\ Y\ R\ O\ V\ J\ D\ S\ S\ L\ O\ F\ F\ R\ H\ O\ O\ SUH\ L\ R\ X\ V\ O\ G\ U\ L\ Q\ N\ D\ Q\ W\ H\ U\)XU\ F\ D\ K\ H\ W\ H\ D\ Q\ X\ Q\ D\ Z\ M\ H\ G\ H\ W\ K\ E\ D\ V\ Q\ Z\ M\ H\ K\ J\ W\ K\ H\ S\ U\ R\ F\ R\ Q\ W\ D\ P\ L\ Q\ D\ W\ H\ G\ Z\ L\ W\ K\ U\ D\ G\ L\ R\ Q\ X\ F\ O\ L\ G\ H\ P\ D\ W\ H\ H\ U\ L\ D\ Q\ W\ D\ Q\ L\ Q\ W\ R\ K\ O\ E\ R\ J\ R\ Q\ W\ K\ H\ Z\ W\ R\ D\ S\ H\ U\ R\ W\ E\ H\ H\ Q\ V\ K\ D\ P\ Z\ S\ Q\ O\ H\ Y\ G\ L\ Q\ Q\ F\ K\ H\ R\ I\ V\ U\ D\ G\ L\ R\ V\ Q\ X\ B\ Q\ G\ G\ H\ V\ V\ X\ U\ I\ D\ F\ H\ Z\ D\ W\ H\ U\ V\ D\ P\ S\ O\ H\ V\ W\ D\ Q\ K\ H\ Q\ F\ K\ L\ W\ M\ G\ R\ W\ K\ F\ D\ D\ V\ O\ W\ K\ H\ Q\ W\ K\ H\ F\ R\ R\ O\ L\ Q\ J\ Z\ D\ W\ H\ U\ U\ H\ E\ K\ M\ D\ H\ U\ G\ J\ H\ H\ G\ H\ Y\ Q\ D\ G\ W\ D\ H\ C\ O\ O\ K\ H\ D\ Y\ H\ O\ W\ [R\ I\ L\ G\ H\ S\ O\ H\ W\ H\ G

&OHDQXS \$SSURDFK

, Q 6WDUPHW FRQGXFWHG RDY F RQXQDMPD QD W\ B\ G\ W\ L\ R\ D\ O\ O\ X\ H\ Q\ D\ G\ Q\ H\ U\ S\ 'HSDUWPHQW RI (QYLURQPHQWDO 3URWHFWLRQ 0\\$'(3 RYHUVLJKH[FDYDWLRQ DQG WUDQVS RQDUDWLRQ XIEGIVFVBDW M RRIODRSRSQW\ DPLPLQD WGHSOHWHG XUDQLXP DQG F RQD\ SWH 7KH HZ\ K\ D\ Q\ W\ H\ D\ Q\ W\ D\ S\ U\ R\ B\ O\ W\ G\ H\ G\ W\ H\ Q\ P\ L\ O\ H\ Y\ H\ O\ O\ S\ H\ M\ E\ R\ X\ O\ G\ Q\ R\ Z\ V\ W\ K\ R\ P\ X\ W\ H\ [F\ D\ Y\ D\ W\ L\ U\ R\ K\ D\ R\ V\ H\ D\ V\ T\ I\ X\ J\ D\ Q\ Q\ W\ L\ F\ W\ D\ Q\ R\ M\ C\ 7KH VLWH KDV VLQFH EH\ B\ U\ Q\ R\ O\ U\ L\ W\ L\ H\ H\ G\ /H\ R\ I\ Q\ D\ W\ K\ B\ X\ M\ U\ D\ R\ M\ Q\ L\ R\ J\ Q\ F\ R\ Q\ W\ D\ P\ L\ Q\ D\ W\ L\ R\ D\ Q\ H\ D\ D\ W\ G\ W\ K\ H\ V\ W\ L\ W\ (3\\$ DXWKRULW\

5HVSQRQVH \$FWLRQ

\$WLPHFULWLFDO\ B\ R\ F\ Y\ R\ D\ Q\ G\ F\ W\ L\ H\ G\ N\ W\ H\ C\ O\ M\ H\ U\ P\ H\ R\ V\ R\ Q\ V\ L\ W\ H\ F\ R\ Q\ W\ D\ L\ P\ D\ W\ H\ U\ L\ D\ O\ 7Z\ R\ J\ D\ E\ X\ H\ U\ L\ W\ H\ K\ R\ V\ W\ Q\ G\ Q\ R\ W\ K\ H\ U\ O\ D\ E\ R\ U\ D\ W\ R\ U\ \ H\ T\ X\ L\ S\ P\ H\ Q\ W\ U\ H\ P\ R\ Y\ D\ O\ D\ V\ V\ H\ V\ V\ P\ H\ Q\ W\ R\ Q\ H\ L\ Q\ D\ I\ H\ Q\ F\ H\ G\ L\ Q\ D\ U\ H\ D\ D\ G\ M\ D\ F\ H\ Q\ W\ W\ F\ R\ Q\ W\ D\ L\ Q\ D\ W\ H\ U\ R\ [G\ R\ U\ X\ P\ V\ W\ K\ H\ R\ W\ K\ H\ F\ D\ O\ O\ H\ G\ W\ K\ H\ R\ O\ G\ O\ D\ Q\ G\ G\ U\ X\ P\ V\ D\ Q\ G\ B\ D\ X\ H\ Q\ D\ W\ S\ F\ W\ L\ W\ H\ H\ P\ D\ O\ D\ F\ W\ L\ R\ Q\ Z\ K\ D\ F\ K\ R\ Q\ F\ G\ O\ X\ G\ H\ L\ Q\ V\ W\ D\ O\ O\ D\ W\ L\ R\ Q\ K\ R\ I\ R\ H\ Q\ G\ F\ L\ Q\ Q\ J\ Q\ G\ U\ I\ R\ Q\ Q\ G\ D\ W\ H\ D\ Z\ K\ H\ U\ H\ E\ X\ U\ L\ H\ G\ G\ U\ X\ P\ V\ F\ D\ S\ S\ L\ Q\ J\ R\ I\ W\ K\ H\ D\ R\ U\ Q\ G\ O\ D\ Q\ Q\ G\ I\ R\ I\ Q\ D\ Q\ V\ W\ Q\ B\ I\ O\ D\ L\ Q\ L\ R\ Q\ H\ L\ Q\ D\ O\ G\ H\ Q\ J\ E\ D\ V\ L\ Y\ Q\ G\ X\ V\ W\ D\ Q\ G\ U\ H\ G\ X\ F\ H\ W\ K\ H\ O\ H\ D\ F\ K\ L\ Q\ J\ R\ I\ F\ R\ Q\ W\ D\ P\ L\ Q\ D\ W\ H\ G\ V\ R\ L\ O\ V\ L\ Q\ W\ K\ H\ Q\ R\ C\ G\ V\ L\ Q\ Z\ D\ V\ F\ R\ Q\ G\ X\ F\ W\ M\ R\ G\ L\ Q\ D\ W\ H\ S\ D\ S\ V\ P\ I\ Q\ U\ S\ U\ H\ Y\ L\ R\ X\ V\ V\ D\ P\ S\ O\ G\ H\ W\ H\ U\ Q\ D\ W\ H\ D\ U\ R\ P\ S\ D\ V\ W\ V\ D\ P\ S\ D\ I\ L\ Q\ W\ D\ H\ U\ P\ R\ H\ U\ W\ Z\ H\ S\ H\ H\ J\ F\ R\ R\ U\ P\ S\ H\ D\ G\ J\ D\ E\ O\ H\ W\ R\ (3\\$ D\ M\ G\ X\ W\ K\ H\ J\ U\ R\ X\ Q\ G\ Z\ D\ W\ H\ U\ P\ R\ Q\ L\ W\ R\ U\ L\ Q\ J\ S\ U\ R\ J\ U\ D\ P\ S\ U\ H\ Y\ L\ R\)

- X Q H V D P S O L Q J H Y H Q W (3 \$ D Q G R V X D P D S @ H Z G W H I G L P Q Q / L W H D
5 L Y H U (3 \$ V D P S O H G W K H J U R X Q I G Q D W H & Q P R Q L W E R H I R Q J H Z M X Q Q Q L Q J
W R 3 R W H Q W L D O O \ 5 H V S R Q V L E O H 3 D U W L H V

3 U R J U H V V D Q G & X U U H Q W 6 W D W X V
5 H R Y D O R I U G X E R I F W B L O G I L L Q R J P E V D Q M B K M P O X Q G H U 0 \$ ' (3 R Y H U V L J K
U H G X F H G W K H W K U H D W R I S R W H Q W L D O H [S R V X U H D W W K H V L W H
S U H Y H Q W W K H K Q I H D H W F V L F A R Q W B / F R W F I R D C F W D V P R L Q D N W B R G D G D W B I Q G U Q Q V D
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VFKHG XOBQDQSMHUIPDS FRC • KWWS ZZZ ZDVWH N\ JRY SURJUD
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&DUSHQWHU & 6 0RUULVQWLIDQGO'R QHWW *Ground Water Currents*, VVXH 1R -XQH KWWS ZZZ FOX LQ RUJ

8 6 (3\$ 3HUPHDEOH 5HDFWVYHR U% & Q MHDUP L7QIBQVR5HRRJHLGLDW
6ROLG :DVWH DQG (PHUJHQL 5HVSRQVH (3\$ 5 6HSV

)HOWFRUQ (DQG 5 %UHHGHQ *Ground Water Currents*, VVXH 'HFHPEHU KWWS ZZZ FOX LQ RUJ DFFH

8 6 (3\$ 2IILFH RI 6ROLG :DVWH SDI/Q *Planned Site in Ground Water Currents* 5HVSRQVH
Flats Site in Ground Water Currents (3\$ 1 , VVXH 1R \$SULO

: D W H U 5 H P H G L D W L R Q *Oilfield Kicks Off Z-92™ Uranium Treatment Process conducted at Brazos Mutual Domestic Water, New Mexico October 21, 2004*
K W W S Z U W Q H W S G R P D \$ G H % U H D G R \$ X J X V W

: D W H U 5 H P H G L D W L R Q *Oilfield Kicks Off Z-92™ Uranium Treatment Process conducted at the Mountain Water & Sanitation District, Conifer, Colorado November 11, 2004*
K W W S P Z S V Q H W W Q F R : D W H U S G I D F F H V V H G \$ X J X V W

: D W H U 5 H P H G L D W L R Q 7 H F K Q R S R J U W / V U 3 L O R E W 8 G W Q G X P 7 U H D
F R Q G X F W H G D W F R Q G X F W H G D W & K H V G L Q 0 D Q R U ' L Q Z L G G L H
& R S D Q \ - X O \ K W W S Z U W Q H W F R P S G I) R [B 5 X Q S G I D

\$ U H \ - 6 - & 6 H D P D Q D Q G 3 0 % H U W V F K ^ , P P R E L O L] D W L
V H G L P H Q W V E \ K \ G U R I *International Remediation Technology Conference and Exhibition - X Q H*
2 U O D Q G R) O R U L G D K W X W \$ H G X Z F F R Q Q W D H L Q M P H Q D V F A M V V H G \$ S U

) H W W H U 6 D Q G) 1 Y R Q S R I V S H C H \ G F B @ H V D H I S U K U D Q L X P P X Q
Global Security

6 W H J Q D U 3 D Q G / % H Q P H G Q N W K H H S O O Y H L W I R Q P X H U Q W Q L D Q L V V X H
Archive of Oncology

6 F K Q R R U - / 3 3 K \ W R U H P W G I U D H V R Q L R Q * U R R Q Q R : O R J L H V \$ Q D C
7 H F K Q R O R J \ (Y D O X D W L R Q

(G H Q V S D F H Case Study: Depleted Uranium *Project Profile: Aberdeen Proving Ground*
K W W S Z Z Z H G H Q V S D F X H P F K R M P P D D V D H F F W X C H Q \$ D X Q X V W

8 6 (3 \$ 3 8 V H R I 0 R Q L W R U H G 1 D W X U D O \$ W W H Q X D W L R Q D W 6
8 Q G H U J Q R Q D J H 7 D Q N 6 L W H V I R 2 6 : (5 ' L U H \$ W U Y @

8 6 (3 \$: H E V L W H K W W S Z U D Z G H B Q X J F O M G B G I X D M D L Q R Q P K W P D

& O H D Q \$ L U \$ F W D V D P H Q G H G B Q & H W V H T

6 D I H ' U L Q N L Q J D D P W H Q U G \$ E W L Q V 8 6 & V V I H W V H T

Nuclear Energy Agency, Organisation for Economic Cooperation and Development, Management of Depleted Uranium \$ - R L Q W 5 H S R U W F D H W U K H Q H & D Q X G J W Q F , Q W H U Q D W L R Q D O \$ W R P L F \$ J H Q F \

8 6 ' 2 (2 D N 5 L G J H 1 D W V R \$ Q P H Q V W E R I U B W H R I U U U H G V ' 8 Q ' V S R V D O

1 DWLRQDO & RXQFLO IRU 5D Gsl D²³⁸U WelsR QPr3ddR W fdnFAwelsR@ 1 & 53
of Internal Radionuclide Deposition.

: RUOG + HDOWK 2 UJDQL] DWLRQ :+2)DFW 6KHHW 1R -DQ
KWWS ZZZ ZKR LQW PHGLDHFQHQ@QH[KDW@P@QKBFRMHW WHG \$XJXV

1 DWLRQDO & RXQFLO IRU 5D G²³⁵U WelsR QPr3ddR W fdnFAwelsR@ 1 & 53
Population of the United States.

: RUOG + HDOWK 2 UJDQR] DWLRQ FWHKSHQW XVPQH@QH@Yeld R
Uranium: Source, Exposure, and Health Effects *HQHYD \$SULO

+ HDOWK 3K\VLFVB@RFLH@Wams foB@ranium 1 0F/HDQ 9\$
2FWREHU

8 6 'HSDUWPHQW RI 'HIHQVH 'R' 2IILFH RI WKH 6SHFLDO \$V
26\$*: , Environmental Exposure Report - Depleted Uranium in the Gulf.
KWWS ZZZ JXOIQOLQN RVG PLO GX DFFHVVHG RQ \$XJXVW

8 6 \$URQYLUHRQMPDO 3RO^{Summary}QPVWLTDXW - Health and
Environmental Consequence of Depleted Uranium Use by the U.S. Army - XQH
KWWS ZZZ IDV RUJ PDQVG@KWR@O DBRQGV@RG \$XJXVW

8 6 (3\$ 2IILFH RI , QGEBRULRSQUDQGG 856 '2(2IILFH RI (QYL
5HVWRUDWL RQ Understan^Ding Variati^Eon of Partition Coefficient, K_d Values. Volume 2: Review of
Geochemistry and Available K_d Values for Cadmium, Cesium, Chromium, Lead, Plutonium,
Radium, Strontium, Thorium, (³H) Tritium, and Uranium (3\$ 5 % : DVKLQJWR
' & \$XJXVW

8QLWHG 1DWLRQV (QYLURQIPWQ@D@V@URQV D&P@QHWDQHGI@Q + XPD
81(3 81&+6 %DONDQV 7D@KH)SRVW@QW@D@ HIIHFWV RQ KXP DQ
HQYLURQPHQW DULVLQJ IURP SRVVLEOH XVH RI GHSOHWG
SUPILQDU\ DVVHVVPHQW *HQHYDHS@RWM@KHU:RUO@L@W@D@QW@
2UJDQL]DWLRQ 'HSOHWG 8UBQG@P@V@D@W@LQRQ@W@W@K@R@V@H@T@X@H@V@
5HSUHVHQWDWLYH RI WKH 6HFUHWDU\ *HQHUDO DQG +HDG R
.RVR YR 810,. 'UDIW 7H[W WK -DQXDUL
KWWS ZZZ HXUR ZKR LQVDFGRHIVX@HQ \$X@X@V@W SG@queous DQJPXL
Environmental Geochemistry 3UHQWL FH +DOO 8SSHU 6DGGOH 5LYHU 1H

8 6 'HSDUWPHQW RI \$JULHFXI@D@X@U@K@6@J@U@L@F@N@W@X@W@K@H@U@Q 3ODI
6\VVWHPV 5HVHDUFK /DERUDWRU\ :LQG (URVLRQ DQG :DWHU
:LQG (URVLRQ (TXD@X@Q@Q@H@W@Q@K@Q@L@F@D@H@U - XQH

8 6 (3\$ Impilation of Air Pollutant Emission Factors AP-42, Fifth Edition, Volume I:
Stationary Point and Area Sources 5HVHDUFK 7ULDQJOH 3DUN 1RUWK & DUR

8 1(3 6FLHQWLILF O L D@P@le@R@U@N@R@n@R@K@R@Y@ Post-Conflict Environmental
Assessment 1RYHPEHU

8 6 (3\$ 2IILFH RI , QGRRU \$LU DQG 5DGLDWHLQ@DDOQG 8 6 '2(5HVWRUDWL RQ Variation in Partition Coefficient, K_d Values. Volume 1: The K_d

Model, Methods of Measurement, and Application of Chemical Reaction Codes (3 \$ 5
\$ X J X V W

& ROHPDQ 5REHUV DQG 0X RQDR I OH S KDIWQH G 8UHDVQH FWLQ 6RL
+DQG +HOG , QVWUXPHQWV ' , \$ (\$ 60 3 3 UHVHQWHG 3X
0HHWLQJ : DVKLQJWRQ '& 1RYHPEHU

: RUOG +HDOWK 2UJDQL] DUURLRQF WHLSRQURM PONQGMW DQ (QYLUR
Uranium: Source, Exposure, and Health Effects * HQHYD \$ SULO

8 6 (3 \$ 2IILFH RI 5D GLD WLRQ Bad Round D P
Final Rules. Vol 1. (3 \$: DVKLQJWRQ '& 17,6 3 %

6LQJK 13 : UHQO 0(WUKR Q\PHSQRWDXOP 5DQ YRFKHPFLDO \$ Q
+DUZHOO (QJODQG 8. 2FWRERHWD O (QYLURQ

.ULHJHU +/- : KLWWDNHU (/ 3UPINBVKHIE BSEWRLRHQWUDHQRG RLQ N
ZDWHU * RYW 5HS \$ QQRXQFH , QG , VVXH 17,6 3 %

8 6 (3 \$ (QYLURQPHQWDO 0RQLW R restricted p D Q G 6XSSRUW / DER
measurement of radioactivity in drinking water. & LQFLQQDWL 2+ (3 \$

/RQJ 6(0DUWLQ 7' QHLWQ B RQH ORH PHQDWFH LQ ZDWHUV D
E\ LQGXFWLYHO\ FRXSOHG SODVPD PDVV VSHFWURPHWU\ U
'HYHORSPHQW Q& 16UHQW PDO 0RQLWRULQJ 6\VWHPV / DERUDWRU

8 6 (3 \$ 2IILFH RI 5D GLD WLRQ ID QRG 6Q GRQ U D\$VW H D Q G (PHUJ
Common Radionuclides Found at Superfund Sites (3 \$ 5 : DVKLQJWRQ '& 0DUFK

8 6 (QYLURQPHQWDO 3URWHFWLRQ \$ JHQF
2IILFH RI 5D GLD WLRQ DQG , QGRRU \$ LU
5D GLD WLRQ 3URWHFWLRQ 'LYLVLRQ
3HQQV\OYDQLD \$ YHQXH 1:
: DVKLQJWRQ '&
(3 \$ 5
'HFHPEHU
ZZZ HSD JRY UDGLDWLRQ